SLOPE STABILITY AND WATER PROBLEMS ASSOCIATED WITH SOIL AND VEGETATION OF INNIS ARDEN

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A.B. Adams and Rob Harrison
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INTRODUCTION

This project's purpose is to classify and interpret the soils and topography of Innis Arden Club Reserves (Boeing Creek, Coyote, Bear Trail, Grouse, Running Water, Blue Heron and Eagle). Our particular interest is to consider slope stability as a function of the soil and surficial geology; and then, how such stability would be affected by: (a) pruning of trees; (b) removal of trees with replacement by shorter growing species; and, (c) continuing erosion of stream channels and watercourses.

To accomplish these objectives, field reconnaissance was done in conjunction with a newly derived soils map for western King County. As a result, we created maps of Innis Arden. These maps are intended to be of such scale as to provide initial guidance to the Club and City of Shoreline in judging the appropriateness, in terms of soil stability, of management activities (specifically, pruning and removal of trees with replacement by shorter-growing species). Because soils are derived from and influenced by parent material, surficial geology was also included in the analyses and conclusions drawn in this study.

Soils were first classified by surficial geology and then field checked. Slopes were classified by USGS 10 meter Digital Elevation Models (DEMs) and then reassessed by field visits (some during periods of heavy precipitation) and the use of 10-foot contour maps. Map layers created and/or provided are soil types, slope classes, surficial geology, parcels (included to provide accurate boundary and location data), reserve boundaries, and 10-foot contour intervals (I map series).

The Innis Arden area is fortunate in that when it was developed, stream channels and habitat were preserved as reserves. The neighborhood provides excellent panoramic views of the Puget Sound and Olympics that sometimes create conflicts between homeowners and slope stability. Although this report alludes to the problems within Innis Arden with respect to vegetation, slope stability and storm runoff, we wish to preface our work with an acknowledgement of the effort already expressed by the residents to protect and preserve the area. The problems we cover in this report are due to the complexity of the geology and soils here (or in some cases misunderstandings) and are not intended to criticize the residents. To the contrary, we are impressed by the respect residents have for the area and hope this report will add to preservation and beauty of Innis Arden.

RISK ASSESSMENT

Based on an overall assessment of risk associated with slope stability, erosion and tree pruning, removal and replacement, we classify areas within the reserves into categories. Placing these reserves into categories is not meant to imply that improper management will maintain their rating; rather it implies that proper management in select areas can allow for shortening the canopy or replacement. In some cases, shorter species at higher densities may even improve stream and storm channel integrity. On exposed bluffs, shorter trees or shrubs might improve stability over other vegetation types due to lowering of wind erosion effects. All Innis Arden reserves are on sensitive soils atop a clay/silt water impermeable area that perches water and may allow soil movement under specific circumstances. The categories are:

1) No Risk – Reserve areas where tree pruning should have no effect on slope stability. These areas have less than 15% slopes, are on Alderwood and/or well drained Indianola soils. Shorter growing species would be acceptable here as replacements. Clay/sand surface contacts (where erosion has exposed clay, often as a shelf, with sand on the higher slopes) are absent. A conifer forest canopy can protect the forest floor, decrease runoff to lower reserves and inhibit invasive species. Removal of the overstory may not be construed as having no overall effect; rather, there is no obvious risk to slope stability within the area in question. No reserves fall into this category.
2) Low Risk – Reserve areas where pruning will have a minimal effect on slope stability on areas with less than 15% slope and/or on compacted till. Replacement with lower-height species is acceptable, and may be used to decrease down-cutting in stream and storm channels. In runoff channels, shorter species at higher densities are preferable to taller species that might be coppiced. No slopes are detected greater than 30% for more than a 60 foot horizontal width. These reserve areas might move into moderate risk if too much canopy is removed and permeable sand is eroded away, or if channel down-cutting increases. Clay/sand contacts are not detectable. Bear Trail and Grouse Reserves are considered low risk areas.
3) Moderate Risk – Areas where pruning may not cause damage in selected spots, but might if mixed with more sensitive areas with slopes greater than 30% and for widths greater than 60 feet. Here, bowed and slanted tree boles indicate slope movement throughout and at least some of the homes are in danger of localized slope movement that could cause movement of concrete slabs. This category includes reserve areas that have a potential for sink hole formation and downslope blow outs, but could be classified as low risk provided corrective action is taken [e.g., Coyote might become a low risk area if the storm water flowing through a culvert could be diverted (CY_O-2)]. Problems associated with a clay/sand contact are present or probable. Coyote and Running Water Reserves are included as well as the upper section of Eagle Reserve (Map I_SO-A).
4) High Risk – Areas where coppicing and replacement with shorter growing species (except in stream channels) is not recommended. Slopes greater than 30% are present and also large areas of greater than 15% slope exist. Stream down-cutting of more than 2 feet is prevalent. Homes may be threatened by slope instability, but the threat is not imminent. Trail location and might affect slope and stream channel stability. Large scale coppicing and tree removal may decrease slope stability. Improper management could affect slope stability in the mid-term term (time scale of decades or within this century). These high risk areas are upper parts Eagle Reserve and sections A and C of Blue Heron Reserve (Map I_SO).

5) Extreme Risk – Areas where native forest stand structure should be maintained and root mortality avoided. Slopes greater than 30% predominate. Slope overburden from organic debris and construction fill have increased slope grade. Surface clay and clay/sand contact are present. All trail construction and maintenance should be done with careful planning for slope stability. Improper management might decrease slope stability in the short term (<10 years). All of Boeing Creek Reserve, section B and D of Blue Heron Reserve and section B and C of Eagle Reserve (Map I_SO) are classified as extreme risks.

DESCRIPTION OF AREA AND JUSTIFICATION OF RISK ASSESSMENT

Plants - Vegetation varies from coniferous forest to deciduous forest and mixes of these two. The conifer forests are mostly classified as mature; the deciduous alders, poplars and cherry forest range from immature to mature. Old growth forest is above Boeing Creek (just south of Innis Arden), but no old growth forests occur within Innis Arden. Some areas within Inis Arden will become old growth in the mid- if left natural. Conifer understory regeneration is common in mature deciduous forests. A few patches of savannah shrubland and shrubland occur. Willows, horsetails skunk cabbage and other riparian plants occur along the streams and in wetter soils.

Invasive plant species are present along the borders and open areas within the reserves, but several reserves have pockets of native understory. Pacific madrones are scattered throughout the study area, particularly on southerly slopes.

General Geology and Slope Stability – The geology of Innis Arden is an association of four types of glacial deposits (Map I-G) overlying bedrock about 3000 feet below. Glacio-lacustrine deposits of silt and clay were deposited when lakes filled the lowlands 15,000 years ago, and possibly during previous glacial periods. This deposited material is referred to as Lawton clay. It has a low permeability to water, except in sand lenses. Advance glacial outwash was deposited over this layer by rivers from glaciers that were advancing southward as the flow of water north and through the straits of Juan de Fuca were blocked by ice. This material is sandy in texture and referred to as Esperance sand. After this, lodgment till (a dense layer of sand and gravel called Vashon Till) was laid down at the base of the glaciers. Thick glacial ice compressed this material such that it now has very low permeability. The fourth layer is recessional outwash. It is similar to the glacial advance outwash except that it is not compacted. It was deposited behind the retreating glaciers and is found on top of compacted till. Sometimes this ablation and compacted till act as a cap on top of bluffs (e.g., at the mouths of Heron and Eagle Creeks) (Map I_SO).

How water moves through these vastly different layers has important implications for slope stability; also, their mosaic like arrangement affects the movement of adjacent deposits. For example, slumps occur when restricting layers occur at several meters or more below the surface especially near vertical slopes of banks and escarpments. Near surface impermeable layers favor the generation of debris avalanches and debris flows. Trees located on shallow surface layers over impermeable layers are subject to wind throw that in turn makes the slope unstable.

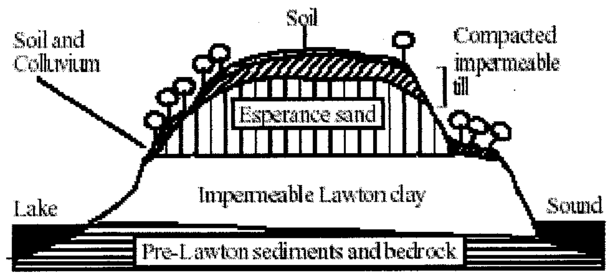


Figure 1 – Geologic Profile of Typical Central Puget Sound Coastal Areas. Lawton Clay (actually fine silt that is slippery like clay when wet) was deposited by a pro-glacial lake. Sand and compacted till were deposited by glaciers. The shelf to the right shows where sand has eroded away. Different soil types form on top of each of these geology types.

Landslides are yearly occurrences on the coasts of the Central Puget Sound. Landslides here often occur where surficial layers of soil rest upon impermeable layers of compacted material such as the Lawton clay (layer of compacted clay deposited by water prior to last glaciation), the Vashon till (compacted), or pre-Lawton layer. Because of the high permeability of the Esperance Sand, water travels through the soil very quickly. As it hits the less or impermeable layer of compacted clay, the water starts to move horizontally. Where gravity pulls the soils (as on the steep hillsides) the chances of less stable layers sliding off the slope increase (especially during seasons of high precipitation).

Soils – Six soil types (see Appendix A for technical descriptions) exist within the study area (Map I_SO). They are: Alderwood gravelly sandy loam; Indianola excessively drained, loamy fine sand; Bellingham silty clay loam; Kitsap silt loam; Entisol (recent slides), Norma (riparian organic) and Arents (fill from human sources). These correspond with normal central Puget Sound coastal soils. Over 95% of the soils within the reserves are classified as Indianola (coarse sand). Pockets of Kitsap silt loam and Bellingham silty clay loam are derived from lacustrine deposits (material that settled from large lakes that existed here thousands of years ago). On less sloped areas atop lacustrine is found Bellingham. It can be distinguished from Kitsap in that the former has distinct yellowish brown redox concentrations. Small pockets and blocks of Alderwood soil atop compacted till are also within the area.

Although external to the reserve boundaries, a large area of Alderwood soil atop compacted, water-impermeable till is located in the central east and northeast parts of Innis Arden. Pockets of Norma were soil series were by Heron Creek in the lower half of Running Water Reserve and in Blue Heron Reserve from a confluence with an intermittent creek to a concrete bridge that crosses Heron Creek just before the stream plunges to the Sound. Atop the bluffs directly over the Sound, a compacted till cap was found at the outlets of Eagle, Heron and possibly Coyote Creeks. The compacted till ledge is very important to the stability of the area in that it holds the sand in place above. Management of the area should prioritize the protection of this highly non-erosive ledge cap.

Alderwood is soil that develops within ablation till (a loose, coarser layer of till deposited above compacted till). The compacted layer is impervious to water penetration and very resistant to erosion. In the upper parts of Innis Arden and upon the cliffs over the Puget Sound, Alderwood soil and its substrata serve as a protective cap. Since drainage is restricted, pools of standing water and flooded basements occur in Alderwood. In some situations, compacted till is important in protecting Innis Arden. For example, compacted till serves as a durable creek bed in some of Blue Heron and Eagle Reserves. Till also serves as a protective cap over some bluffs.

Indianola is a sandy loam soil. It is well drained and has few coarse rocks. Vegetated (and, in particular forested) Indianola absorbs water rapidly and is stable with normal runoff. It does, however, erode very rapidly with urban storm surges, when the overstory vegetation is disturbed, with heavy trail use or with even light foot traffic on slopes off established trails. Lack of permanent stream courses over Indianola soil are due to: 1) lost of vegetation and soil structure; and, 2) rapid infiltration into the soil of precipitation. With composting, Indianola can be a good garden soil.

Bellingham and Kitsap soils occur together throughout the reserves in proportions that make it difficult to call them one or the other soil type. In some cases they are only minor components of these 2 series in what is largely an Indianola unit (e.g., in Boeing Creek Reserve). Bellingham and Kitsap are both derived from clay parent material. Kitsap is well-drained silty loam, whereas Bellingham occurs in areas that have sufficient water to cause redox mottling (orange and brown spots). These are mineral soils, but Bellingham may contain some peat.

Entisol is an order (as opposed to series) classification It refers to soil so recent in its origin that no organic matter has accrued and no weathering has occurred. In the Innis Arden area, Entisol refers to a large area of recent slide activity (Map I_SO). This area is relevant to the report because it is downstream and associated with Coyote Reserve.

Arent refers to soil derived from anthropogenic influences. In Innis Arden some material is deposited into the creeks and more as organic debris on reserve borders. Fill includes leaves, grass clippings, branches, whole trees, tires, slabs of concrete, paint buckets and shoes. Construction and organic debris deposited on the borders of reserves causes slope overloading and even filling of creek beds (Figure 1). Arent is also at the mouth of Boeing Creek as a result of railroad track construction. Often organic debris is deposited atop construction fill resulting in very steep and unstable slopes.

Norma is a soil series that occurs in narrow strips along Heron and Eagle Creeks and perhaps in pockets in Boeing Creek. It is a poorly drained soil formed in alluvium and in this case under conifers and hardwoods with sedges, horsetails and willows growing in it. It occurs where slopes are generally <2%. The surface layer is black sandy (gritty) loam to 10 inches thick. Below this, the subsoil is grayish brown. In Innis Arden these probably represent relict wetlands. It is a organic soil with sand particles that can be readily detected when the soil is rubbed between one's fingers. It is a riparian It soil here and is indicative of relict wetlands. It is characterized by the presence of black oozing mud and skunk cabbage.

Slopes - Slope analyses indicate that large areas (>400 m^2) with slopes greater than 30% exist in all reserves except for Bear Trail (Map I_SL). Overall the Innis Arden neighborhood is a landscape of terraces and moderate (10-30%) to extreme (>30%) slopes. There are two basic kinds of steep slopes. First are natural slopes of mostly Indianola soil. Secondly, are areas of fill pushed over in staging activities of home constructions and fill brought in and/or pushed aside for building roadbeds. Slope derivations with DEMs showed the former, but not the latter. The reserves contain much of the steepest areas and these are forested. These problems exist on the west and northwest boundaries of Coyote in lower Grouse Reserve, and both sides of Running Water, Blue Heron and Eagle Reserves. This also applies to the trail (Map BC_O) in

Figure 1 – Road cut showing slope grade increase due to the deposit of cut material downslope.

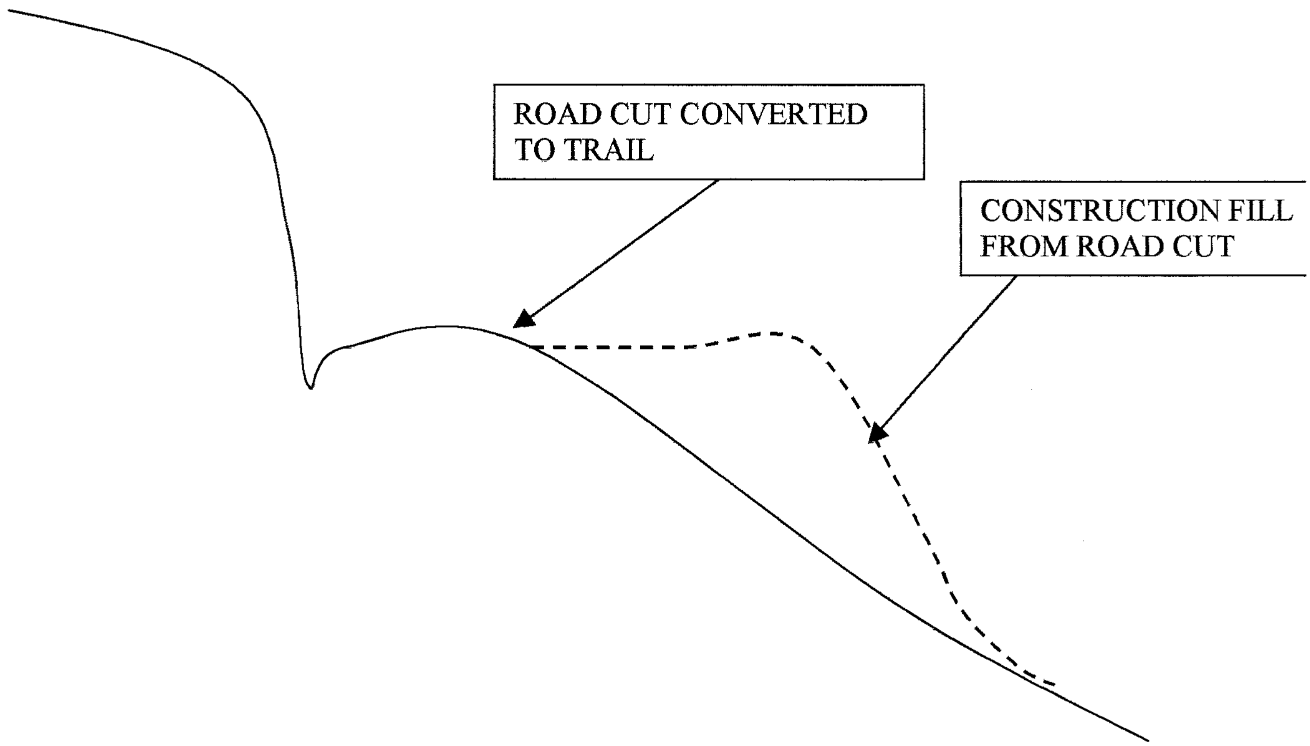
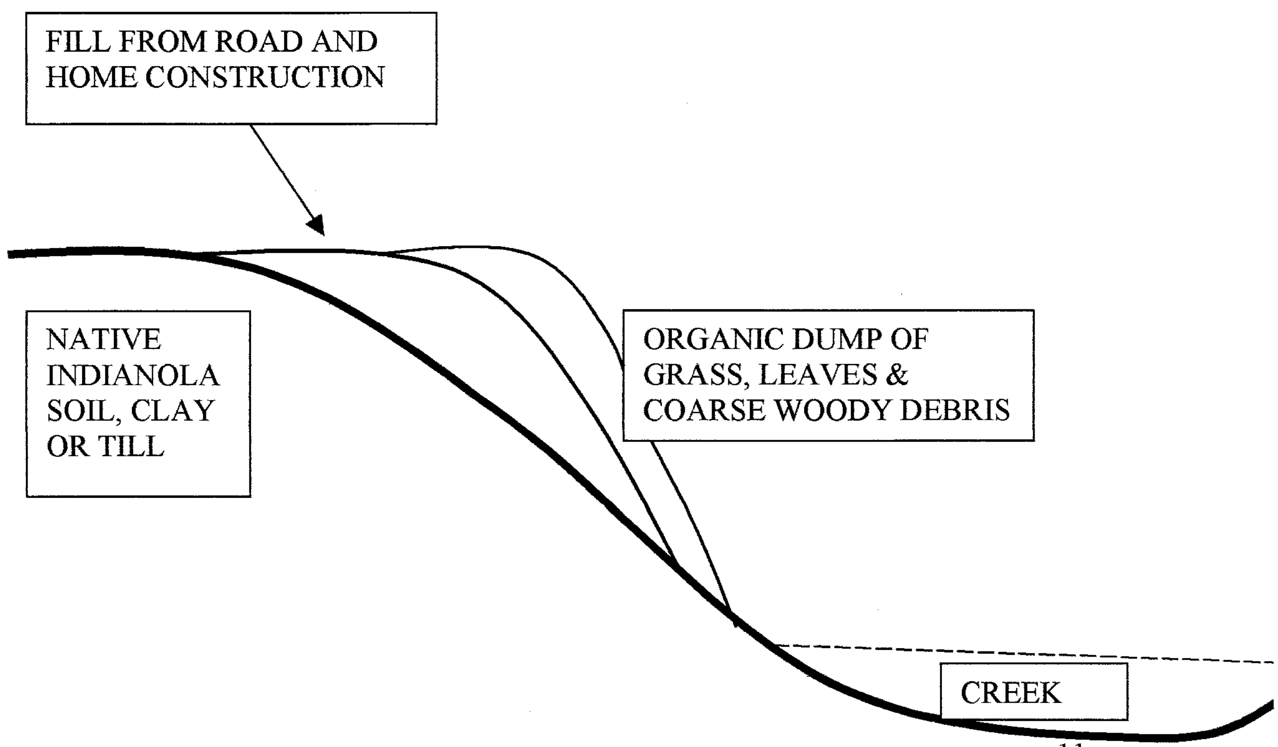


Figure 2 – Slope grade increase in watersheds associated with sequence of events. First fill material from construction (road or home) is deposited downslope. Secondly, organic debris is deposited on top of construction fill. Resulting overburden leads to debris slides.



Boeing Creek. Whenever roads cross through or are adjacent to the reserves, slopes with >30% exist (sometimes >60%).

Overloading slopes with perpetual sidecast cause slope failures with ground slopes steeper than 70%. These failures are common on convex slopes, mid- to upper-slopes and colluvial soils. On some wet soils the failure angle can be much less, and in the Innis Arden reserves with their sandy soils, 55-60% represents a maximum ground slope for stability. Sidecasting is caused by road and home construction, and currently is aggravated by the ubiquitous deposit of organic yard waste into reserves. On steep slopes that have little cohesiveness, slope gradient is a major indicator of landslide hazard with overburden.

Erosion hazards on Indianola are listed as moderate to severe. Permeability is rapid and runoff is medium to rapid. The reserves are largely Indianola soil and referred to as Capability Unit Vie-1 on slopes greater than 15% slope. This means that .."Because of erosion and droughtiness, they (the soils) are better suited to permanent vegetation, woodland, wildlife habitat and recreational use…" (Snyder, et al. 1973). Although permanent is not defined beyond what is stated here, we assume that coppicing and tree removal should not leave a slope >15% barren during the rainy winter season.

The lack of bedrock in conjunction with the deep sand means that slope stabilization by the anchoring of deep basal roots in bedrock cracks is minimal. Instead, slope stabilization by plants is a function of lateral root networking and root block formation. In such a situation excessive topping or logging causes a rapid build up in dead roots that provide less slope integrity than living roots with their interconnected lateral root network. Any trees growing within the watershed that are to be coppiced should respond to this, but overall setbacks in canopy leaf biomass may result in a weakening of the lateral root system. Alders, poplars, maples and members of the Cupressaceae (e.g., western red cedar) respond well to coppicing and presumably maintain an intact root system.

Significant canopy cover by conifers in the reserves leads to loss of water from evapotranspiration. Removal of water by the plants from the soils will increase slope stability. In addition, interception of precipitation by the canopy can slow down the infiltration of water into the soil. This prolonged released of water from the canopy to the soil was observed to be as much as 2 hours. The overall effect of this is to lower rill (over the surface) erosion and decrease stream urban storm surges. This effect is of much greater significance for snow events that when followed by heavy rains have the greatest potential for creating catastrophic slope failures.

Observations within the reserves indicated that topping (in particularly coppicing) may result in colonization by mountain beavers (Aplodontia rufa) (Hacker 1993 and see Appendix 2) and noxious, invasive weeds. Mountain beavers in large numbers can increase slope instability and lead to stream siltation. Invasive shrubs and herbs can destroy community structure needed to support wildlife, outcompete native plants, impede movement as well as be unaesthetic. Mountain beavers can be limited by the removal of coarse woody debris following pruning and tree cutting. Removing coarse woody debris will also improve slope stability. Responses to tree topping are accentuated due to the soft soil and small upper soil horizons (O and A). Perhaps rodent and invasive plant control could ameliorate these problems if done at the appropriate time after coppicing or tree removal.

Conditions associated with sink hole formation, wash outs and landslides exist in Innis Arden. Such events are more likely during major rain-on-snow episodes such as occurred during the 1996-97 holiday season when the bridge over the North Fork of Boeing Creek washed out. Several explanations exist for the cause of this event (including piping, skewering, overflow associated with ice and snow clogging the drains into an inadequate retention/detention facility). These problems are associated with construction on glacial deposits found in coastal areas of the Puget Sound. Although such processes are inevitable with the passage of time, the time frame is reasonable for generations of humans provided proper respect is given to the forces at work. In particular, steep areas of sandy soil over clay deposits should not be devegetated or topped. Both harvesting and coppicing lead to root death that decreases soil stability. Some trees of the northwest do respond well to coppicing [e.g., trees of the Cupressaceae (red cedar), alders poplars, big leaf maples and willows]. Although topping of any trees in the lower reserves (Boeing, Blue Heron and Eagle) should be avoided, topping in the upper reserves should be done with prudence and with respect to slope stability associated with soil type, canopy and root integrity. Conifer canopies are best suited for canopy interception of rain and snow. These help by lowering and lengthening the storm runoff, especially during the rainy season. Pacific madrones do particularly well in terms of canopy interception and slope stabilization, but these trees do not respond well to coppicing and excessive erosion or compaction.

An area of compacted till exists at the surface just above the bluffs above the Sound over the mouths of Eagle and Heron Creeks. This cap serves to stabilize the current land above the bluffs, but is being subjected to focused down cutting from urban storm surges not typical of normal stream flows. Mismanagement (for example, grading) of this compacted till over the bluffs can lead to increased incidents of slope failure similar to episodes that happened on Magnolia Bluffs and in the Des Moines areas.

Down Cutting and Other Water Problems - A problem in the reserves is severe to moderate down cutting in Boeing, Blue Heron and Eagle Reserves. Down cutting of the stream channels is caused by storm surges associated with urban runoff. Home and road construction redirects water onto unstable sections of a slope. This increases the hydraulic pressure in the soil and reduces the forces that hold it in place. The problem is aggravated by the placement of drainage pipes directly into the reserves, or in some cases placing outlets directly on or over steep slopes. Such outlets cause washouts and gullies. One example of where this has been catastrophic is in the King Co. Natural Area where drainage through a pipe has caused as much as a 100-foot recession of the land in recent times. Water should be transported directly to sewers, the Sound or stored on site. A second, more difficult problem is associated with runoff from urban pavement and rooftops. Innis Arden is particularly sensitive to storm surges due to the highly erosive nature of the soil found there. For Boeing and Eagle Creeks, a solution requires planning over a larger area and extends to neighborhoods outside of the Innis Arden area. In contrast, water to Heron Creek is generated internally and can be solved with local solutions.

Stream bank stabilization can ameliorate part of the down cutting problem in the streams. Nonetheless, until the problem with urban storm surges due to urbanization is sufficiently addressed, any bank stabilization work in Eagle or Boeing Creeks may be washed out within short order. Trail and children activities may also interfere with bank restoration attempts. Education and providing alternatives are possible solution.

Upper Boeing Creek is down cutting through sand and the surrounding slopes are largely Indianola soil. Upper Eagle, Running Water, Grouse and Bear Trail Reserves have surface streams running on sand, but many of these areas are very intermittent. Lower reaches of Boeing, Heron and Eagle Creeks run atop clay, but Heron and Eagle cut through till and sand at their mouths.

THE ROLE OF PLANTS IN SLOPE STABILITY

Canopy/Trunk - There is an equilibrium between leaf and root biomass. When leaf biomass is high, lateral root biomass is high; when leaves are pruned or harvested, root biomass decreases. Post-cutting decrease in slope stability is caused by increased slope saturation (Ziemer 1981) and/or decreasing root reinforcement. Trees reduce soil saturation by interception, transpiration and inhibition of rain-on-snow processes [e.g., the 1996/97 Holiday Storm Event (Gerstel, et al. 1997)]. Barren, exposed soil is never a solution, but often a problem with respect to slope stability and watershed quality. In contrast, a full canopy with a well developed understory often increases slope stability and watershed quality. This does not, however, preclude beneficial effects or neutral differences with respect to using different tree and shrub species, some of which may be of different heights and respond differently to pruning. On bluffs with a durable soil such as Alderwood, for example, shrubs and small trees may anchor into compacted till better and avoid damage associated with wind falls. Cover per se is not always a perfect objective, as too much emphasis on a monoculture of a species adapted to poor or unstable soils (e.g., kudzu or Scots broom) can result in habitat destruction and other problems.

Roots and Litter – Shallow lateral roots interweave extensively, forming a reinforcing mat that spans unstable sections of a hillslope and prevents failure (Krogstan 1995). The strength of the root mat is proportional to the strength of the root wood, the stand sapwood, basal area, the spread of the root systems and root orientation. After pruning, thinning or total timber harvest roots decay and slope stability is reduced until young trees grow enough to replace them.

Decay of roots causes a significant increase in landslide frequency and soil mass movement. The root system integrity is related to canopy leaf biomass and plant species and growth form. Most of the tree root mass is in shallow soil near the stump and this area is stronger than the soil around or below the tree. Slope failures often occur midway between or below these tree root blocks. Other roots do, however, extend laterally to trees in the proximity. As they do so, roots interweave and hold these blocks together. Such an intact root network increases overall slope stability. Although basal roots may increase stability, there ability to do so is limited in the Innis Arden area because the possibility of anchoring into underlying bedrock is minimal due to it's large distance below the surface. Blocks of soils held in place by basal or lateral roots act to buttress less stable blocks upslope, thus preventing slope failure.

In many cases the health of madrone trees is in decline, and one can assume that these unhealthy trees are a source of dead roots. On the other hand, some madrones are very healthy. In general, healthy madrones occur in sandy, well-drained soil with little disturbance to the forest floor. Healthy madrones stabilize slow moving sandy slopes, whereas unhealthy, dying madrones destabilize the slopes. Healthy madrones should not be coppiced nor removed on steep slopes.

RESERVE SUMMARY

Boeing Creek Reserve - Assessed as Extreme Risk due to steep slopes, clay/sand interface, high flows during storms and evidence of previous slope movement. This reserve is on the north side of the lower reach of Boeing Creek (also called Hidden Creek). The overstory is mature deciduous forest (mostly alder and maple) and a well-developed understory with healthy conifer (western red cedar, western hemlock, grand fir and some Doug-fir) regeneration. The stream runs all year. Storm events bring on large, rapid increases in stream flow volumes. Flow volume quickly recedes with the cessation of precipitation. Most of the creek water comes from the upper watershed east of the reserve. In particular storm runoff from Shoreline Community College and the Sears Mall contribute to the surge in runoff of the stream despite two retention/detention ponds in Boeing Park..

The main trail is along a deactivated road that was originally sliced and filled along a steep, south-facing slope. All soil within this reserve is classified as Indianola. There are patches of soil with horsetails growing where springs emerge and flow on the surface. These are units of Bellingham too small to map. It has deep, fine sand. Along the northern reserve boundary and northward to the top of a very steep slope (BCO-1) organic debris dumping and construction fill have steepened the slope and created an overburdened slope. Continuation of this practice will continue to decrease slope stability. Moving from the gate roughly 200 feet westward along the trail a large slump area exists (BGO-2). This was caused by a road slice's material that was deposited downslope leading to the slump. The road fill was pushed west to block the drainage of a cove running north. Here (BCO-3 and 4) pits (potential piping areas) occur up slope. The first of these drains through a narrow culvert, the puddles water before it slips under the road through a bent culvert. Both sites could wash out with a snow-on-rain event. The road surface is clay. Just beyond this is a fenced tank (BCO-5). Horsetails, springs and clay suggest that the road was cut at a clay/sand contact. Soil above the road is sandy (Indianola), but clay is exposed on the steeper, eroded areas. Below here (BCO-15) is still sandy soil, but exposed clay becomes more noticeable. The forest here is mixed mature deciduous and conifer. Conifer saplings in the under story appear healthy, but are not prolific. At BCO-6 a 12" culvert drops 100' off an embankment. A large gully has formed where this culvert formerly spilled onto midslope. A new 6" culvert has been placed with the larger pipe and is apparently buried

Soil north of BOG-6 is deep sandy loam. At the clay/sand contact a recent slide is noted. Below the slide site, a sub-basin opens with milder grades (15-30%). It might be tempting to top trees here, but bowed and slanting trees suggest that this area is in motion and best be left alone. Indeed a very large slump is just west of BCO-7. BCO-8 and 9 are springs that surface just above the trail. Robust vine maples are seen here indicating that they will do well on these slopes. The former seeps into the road bed, whereas the other goes through an 18" culvert installed a 5 years ago. It transports water well during heavy rains. A vast, steep slope BCO-10 with shrubs and sparse tree canopy occurs to the north and northwest as the trail bends to the south and descends to the stream. A forest should be reestablished here, and it might even be best to plant trees with low statue here. This is a good site for madrones, vine maples and elderberries.

BCO-11-13 represent areas of restoration at the mouth of the creek. The restoration work here seems to be working. BCO-11 is an overflow channel that diverts water during times of heavy runoff. BCO-12 is well-constructed bridge with large organic debris (stumps) and rocks protecting the north embankment; under the south end of the bridge the creek is undercutting the bank and may eventually wash out the bridge. This embankment needs protection. BCO-13 is a large log barrier that makes the stream meander to the north. At BCO-14, looking south and old bridge site can be seen in which channel debris is slows the stream when volumes are high. During this study salmon were spotted swimming upstream at BCO-12 and 13.

The geology map (BCG) shows that sand occurs on top of clay along the north border of the reserve. This contrasts with the south side of the lower watershed where compacted till occurs directly above the clay. This side also has mature and old growth conifer forests that seem to be holding these slopes in place. Although stream down cutting in this creek runs from moderate to severe, attempts at restoration will prove futile unless very large debris such as that used at BCG11-13 is used. The high volume of water present in the stream during storm surges will wash out restoration projects. The large of amount of siltation into the Sound from this creek is noted in the water at and north of BCO-17. There is a need for plant restoration in this reserve, especially on the slope associated with BCO-10 and a need for very large organic debris (logs or stumps in Boeing Creek. Topping or removal of trees is ill-advised in this reserve; nonetheless, shorter growing trees and broad leaf evergreen shrubs (salal, Rhododendrons, etc.) might be work well for exposed ledges above the north border of the reserve.

Down cutting is moderate to severe throughout this reach of lower Boeing Creek BCO-12 and 13. Peak flows are so large and strong during storm events that even the best intentioned restoration projects are in jeopardy of being washed out within the same season they are installed. It would be more effective to focus on decreasing storm runoff volumes from areas upstream unless heavy equipment able to move large logs and stumps into the stream were available.

Coyote Reserve – Assessed at Moderate Risk due to steep slopes, evidence of slope movement, side culvert and potential for sink hole formation. This reserve is in the center of the neighborhood. There is no trail in Coyote Reserve, and it can only be entered by descending steep (>30%) slopes that surround all sides of the reserve. The reserve is on a strip of sand that lies between a till cap (Alderwood soil) to the east and Lawton clay to the west. No pruning or tree removal is recommended for this reserve due to the its relationship to the unstable area immediately below.

The soil is loamy sand (Indianola) over deep coarse sand. Rain fall and runoff into this area immediately percolates into the sand (creeks are shown on old maps indicating that a stream was present prior to development). The water resurfaces below as a stream in the King County Natural Area where a clay/sand contact surfaces. Sand and, to a much lesser extent, till have been pushed into the reserve at the borders from house and road construction. For these reasons the west and northwest borders have steep slopes (30-70%) (CY_O-1). These steep slopes range 10 – 20 meters in width. A retaining wall/compost complex exists at the southwest corner of the reserve creating a escarpment. Organic debris dumping occurs around the reserve borders. In several cases this has created slopes with angles of repose much >50%. Some tires and concrete have been deposited into the reserve. The area just to the south of the border is very steep. Only the bottom and eastern border of the reserve are less than 30% slope. Large steep areas continue above and to the east and southeast of the reserve.

Culvert

Tree growth forms indicate slope movement and soil creep along both sides of Coyote Reserve. The west culvert drain is half open (CY_O-4), but does not collect water even during the heaviest of rains. This culvert would, however, be needed as a drain during a rain-on-snow event. The mixed conifer/deciduous forest canopy here delays precipitation runoff. Although there are no immediate problems with severe down cutting or surface infiltration here, the debris filling may resulting in localized slides that block the partially functioning culvert. This might result in flooding in a rain-on-snow event. The fill brought in for construction of the roads is presumably coarse textured material that would be less likely to wash out. Moderate Mountain Beaver activity is found throughout Coyote reserve.

It does collect water

A mature deciduous forest of alder and some maple dominate the canopy. Many of these trees are slanted indicating soil movement throughout the reserve. Slope failure could result in culvert blockage, but there is no indication of the potential of other types of catastrophic events here. The undisturbed understory is in good condition.

Since Coyote Creek has coarse sand of great depth below sandy soil, rain and storm water percolate rapidly into the soil limiting runoff. No creek or storm flow occurs in Coyote Reserve, but a creek that runs year round emerges in the King County Natural Area below. This creek is diverted by a recent slide (CY_O-7). Because of this blockage, there is no clear outlet to the creek, but rather a diffuse area of seepage through slide material in the King County Natural Area. We assume that water percolating into the soil of Coyote Reserve emerges with this creek. A 12" storm culvert (CY_O-2) delivers large amounts of water into Coyote during rain storms. The water puddles in the middle of the reserve (CY-O-3) but rapidly goes into the soil. A gully is growing between the culvert and the bottom of the reserve as water is dumped into the reserve. This situation should be corrected. Otherwise an even larger gully will form and the large volume of water passing through the sand may create a hydrostatic head lower down causing a blow out and the subsequent transport of sand from the reserve to lower cliff (sink hole formation).

The Esperance sand area (CY-O-5) lies directly upon clay with no till cap between it and surface clay (CY-O-6). This has resulted in slides, slumps and debris flows below (CY_O-7). Any action taken to decrease subterranean water flow through this area will increase the overall slope stability of the central portion of Innis Arden.

HERON/EAGLE CREEK RESERVE COMPLEX – This is a series of 5 reserves (Blue Heron, Running Water, Grouse and Bear Trail and Eagle) in 2 similar watersheds (Map I_O). Grouse and Bear Trail lack surface streams except during storms. A spring emerges in Running Water Reserve, and it continues through Blue Heron Reserve to the Sound. A confluence of a north drainage occurs in the upper third of the Blue Heron Reserve. Like Coyote Reserve, all water in Heron Creek is comes from the Innis Arden area. Eagle Creek is to the north with a stream that runs year round. Yard waste dumping is a problem along the borders of all these reserves.

Bear Trail Reserve – Assessed at a Low Risk. It is the upper most reserve of the Blue Heron Complex. Surface and subterranean flow was seen (HE_O-4) during a heavy rain and the culvert at the west border is functional. It is all well-drained sandy loam with excellent infiltration potential. There is a site (HE_O-3) of excessive mountain bike activity that is threatening some large conifers and may result in wind throws of large Douglas-fir and hemlocks. There are few other signs here of damage due to recreational activity. Yard waste dumping is a problem on the reserve borders. Down cutting is low to non-existent. A 12" storm culvert empties a considerable amount of water into the reserve (HE_O_5) during storms. By diverting water from this storm culvert, down cutting farther down stream could be lessened.

The canopy is a mature mixed forest with a patch of invasive shrubs in the upper third of the reserve. The steps dropping into the upper part of the reserve are being undercut by circumnavigation by pedestrians or most likely, mountain bikes (HE_O-2). The trail is otherwise in good shape. There are some signs of slope movement here, but much less so than in the other reserves. Flickers are present.

Grouse Reserve – Assessed at Low Risk. It is located directly below Bear Trail Reserve and water flows only during storms. It is all well-drained sandy loam soil with excellent infiltration properties. The area is mostly immature to mature deciduous forest on the borders and lower end, but there is an upper grassy, savannah patch with transplanted Quercus Kellogii and Fraxinus oregana (Oregon ash) and Scots pine. During storms, significant surface flow occurs, but erosion is slight. The restoration work with shrubs and short trees has been effective in slowing runoff and protecting the soil Adding more shrubs and short trees here would limit invasives and improve storm flows. Down cutting is not low. There is evidence of some creep along the steeper borders that again are >30% (HE_O-1). The upper third is immature deciduous and below the shrubland/savannah area (HE_O-6) is a larger mixed forest with some evidence of coppicing of alders and maples. It appears that lots of material was pushed into the sides of this reserve with road and home construction.

The trail is good to moderate, but the upper part could use some drainage bars. It looks as though the trail entrance was moved slightly to the south some time in the past. The outlet culvert (HE_O-7) is functional. There is no sign of catastrophic problems here unless there was culvert blockage and a road washout. The homes that border the south and in particular the northwest of this reserve are next to slopes >30% (HE_O-7) and could initiate slope movement and flows with vegetation removal or excessive activity.

Running Water Reserve – Assessed at Moderate Risk due to steep localized slopes, soil sensitivity, possible clay/sand contact (HE_O-9) and soil movement noted by tree bole shapes and angles of repose. This reserve is downstream of Grouse Reserve. A creek that emerges in the reserve center (HE_O-9). Appears clear and maintains a steady flow even in heavy rains. Down cutting is light to non-existent both above and below this creek. The creek is surrounded by healthy riparian vegetation that both improves flow qualities and limits excessive visits by hikers. The lower half of this reserve may be a relic wetland because sandy organic soil (Norma) occurs along the creek here. The creek emerges most likely along a contact of esperance sand with either clay or compacted till and this explains why the creek runs along the surface. Stream down cutting is not present in this reserve

This reserve has a good canopy cover. The trail head (HE_O-8) has a healthy madrone to the north that may be holding the slope in place there. The upper entrance has immature deciduous trees with scattered conifers. The trail drops steeply along road construction fill. These steps are good, but will have to be replaced sometime over the next 10 years. There is serious weed invasion from this entrance of blackberries, morning glory and English ivy. The lower two-thirds of the reserve is mature deciduous forest (mostly alder) except that extensive coppicing has occurred at the northwest boundary of the reserve, and again with the effect of encouraging invasion by invasive plants. Conifer regeneration is occurring within this reserve. Plant understory is in good shape in the central area of this reserve. Alder logs have fallen into the creek and pools are prevalent. Vegetation acts as a habitat barrier, preventing people from getting to the stream without a struggle.

Steep slopes occur on both sides of the reserve, again enhanced by construction fill and yard waste. The southwest border is particularly step over a narrow width (HE_O-1). Mountain beaver activity is moderate. The trail runs along the south side and a skid trail comes into the reserve from the south roughly where the spring is. The stream exits through a culvert that is covered with weeds and inaccessible as such. The outlet culvert is functional. A pipe apparently feeds into the stream under the road here (HE_O-10), and this is supported by the increase in the volume of water noted at the entrance to Blue Heron Reserve. Diversion of this storm pipe could limit storm down cutting down stream.

Blue Heron Reserve – Assessed as High Risk (Sections A and C of Map I_SO) to Extreme Risk (Sections B and D) due to slope classification, down cutting, undercutting and clay/sand contact. In general this reserve has higher storm volumes, greater slope movement, more down cutting than the other 3 reserves in this watershed, but less so than in Boeing and Eagle Creeks (except for the mouth of Heron Creek). There is no trail as the creek enters the reserve (HE_O_11) by dropping approximately 5' onto a well-established big leaf maple. The maples roots and bole provide a good landing platform for the small falls, thus making this tree poor candidate for pruning. There is a mature deciduous forest here with western red cedar conifer regeneration. In addition, a number of immature cherries (Prunus emarginata) are here.

Approximately 50 yards from the east boundary and along the northern border (HE_O-12), an open area was found to be soft Indianola soil. Mountain beavers colonize such sites if small and coarse woody debris both are present. Similarly, invasive plant species (morning glory, several blackberry species and Japanese knotweed) colonize open border areas. The north side of the creek is impenetrable shrubland. Narrow bands (<20 yards) of steep slopes drop into this watershed on both sides (HE_O-1). A trail enters over a large yard waste dump (HE_O-13) and crosses a makeshift plank mountain bike bridge and ramp. The trail continues to a heavily used kid swing area just above HE_O-15. Between the streams entry to Blue Heron and the clay/sand contact downstream (HE_O-15) down cutting is moderate. This reach is a good area for stream bank stabilization using natural materials (bioengineering). From HE_0-15 the creek moves south with low to non-existent down cutting. There is a dense mixed mature forest canopy here.

The middle area between the confluence with an intermittent side branch (HE_O-14) to a well-constructed concrete bridge (HE_O-18) near the mouth has low (on clay and till) to a noticeable presence of down cutting. In the upper section the stream runs across rocks atop sand, but below HE_O-15 the streambed runs directly upon compacted till with organic soil (Norma) (I_SO). Approximately two-thirds the way down this reserve, the creek runs directly on clay with compacted sand on the banks above. Down cutting is extremely severe here. Down cutting is present at the top of the reserve, but logs are falling into the stream and is not too bad as it would be with no large organic debris. The stream moves onto till here (HE_O-17), but has cut sliced through it in spots. Passage here to the concrete bridge is difficult in the summer due to the dense native understory. Mountain beavers are common here. The canopy becomes immature to immature deciduous forest here. Willows are in the channel here. More small trees would help here. Trees and shrubs of short statue might suit the top of the south canyon here, but the north bank is too big and steep to modify.

At the lower third of this reserve, the creek passes through an area of coppicing above the south bank and then passes 20 feet under the concrete bridge (HE_O-18). An excellent stairway has been built on the trail north of this bridge, but people or circumnavigating the steps to the west. This route will eventually undermine both the steps and perhaps the shallowly rooted trees growing on the till here. The coppiced areas are now dense Himalayan blackberry patches with mountain beaver activity. It then descends rapidly through the clay, then compacted till and finally severely undercuts the till by moving into sand at the bottom before entering the Sound. This has created a till overhang that will most likely collapse or calve soon. The canyon ends with a mature conifer overstory. Two 6 inch pipes dump directly into the creek here. These should be diverted directly down to the Sound.

A catastrophic slope failure may be imminent at the creek's mouth (HE_O-18) where the stream runs under a bluff and undercuts a very large section of compacted till overlying sand. The creek moves forcefully through the sand under the till especially during urban storm surges creating an unstable overhang. The trail is directly above this undercut area. A very large, ominous (~50 feet high) bluff of compacted till is to the north of the stream here. Cliffs on either side of the stream are in danger of collapsing.

Eagle Reserve – Assessed as High Risk (Section A of Map HE_O) to Extreme Risk (Sections B and C) due to steep slopes, clay/sand contact, down cutting, slope disturbance by trail and kid recreational activities and descent off of cliff. At the top of this reserve creek enters at NW 188 and 15th NW after meandering for some distance through the backyards of many homes (HE_O-21). The creek runs year round and much of the water comes from outside of Innis Arden. Steep slopes are found on both sides of this reserve with widths of 30 to 100 horizontal feet that have slopes greater than 30%. No slopes surrounding the creek are less than 15%. Mountain beaver activity occurs throughout the reserve at a low to moderate level. The top of the reserve is an alder/madrone/cedar (mature mixed) forest. Soil creep and slope movement is indicated throughout this reserve. The amount of flooding upstream of the reserve would be worth investigating since this might tell you how much of the water at high stream flows comes from above and how much is generated by water from Innis Arden. The stream above the reserve is rip rap. Water drops 5 feet into the reserve from a culvert. The trail entrance is poorly graded and drops rapidly to the stream where the trail becomes good. This good trail runs about 10 feet above the stream, but then drops to the creek as the slopes steepen and the reserve widens. Where the creek starts to curve to slightly to the southwest, a bad skid trail and some concrete blocks occur. Down cutting is moderate to severe in the upper third of this reserve. Restoration work on this upper section requires large organic debris.

The grade of the creek and trail increase as you pass an area of 24 inch abandoned culverts. From this point the trail deteriorates with slumps common as you cross a good, newly installed (King Co.) double log bridge to the north bank (HE_O-22). Stream down cutting here is moderate. The downstream side of the bridge needs steps, and the trail is undercutting some large conifers. After the log bridge the trail improves and stream down cutting lessens. Slope is >30% on both sides throughout the reserve. Several skid trails appear at a second bridge (made of planks). There is a swing here and lots of north/south pedestrian (mountain bikes?) cross traffic evident. The traffic is damaging the vegetation, slopes and stream bank. Approximately 75 yards down from this point is a third makeshift bridge (this one with concrete pilings). Between the second and third bridges the trail runs precariously on the north side with numerous slumps. Large trees are threatened in several cases. Sections of the north hill side are in danger of collapsing into the stream here. The trail could be moved to the south side of the creek. Down cutting in the stream is from moderate to severe over this stretch. Another area of swing activity is located at the 3rd bridge and again there is evidence of heavy cross traffic. In one case to the north a gully has formed, due to cross traffic or a former culvert outlet. The forest remains mature mixed but at the second bridge becomes almost predominantly conifer with lots of regeneration. Both plank bridges (HE_O-23) are non-permanent. A concrete slab in the creek just below bridge #3 (the plank bridge) could serve better as a crossing on most days. The forest is pure maple at one point between the plank bridges, but then returns to mature mixed forest

From the last plank bridge to the road the trail is good and the stream levels off onto till (it was running through sand before) for the last 100 yards. Pruning and tree replacement are not recommended here because of the complexity of the slopes and soils above and below this area (HE_O-23 to 24). The forest becomes mostly alder and then returns to mature mixed forest. At the mouth of the creek and in the reserve west of the road, a series of weirs have been installed. After cascading through the weirs, the creek drops 1-200 feet into the Sound. Here down cutting is severe as the stream slices through till. A culvert outlet continuously empties and erodes the bluff face here (HE_O-26). This culvert should be removed. directly onto the stream bank and bluffs here, and this situation needs correcting. This bluff profile provided by the stream down cut here and at the mouth of Heron Creek provide ample evidence that the bluff is capped with compacted till that is holding a large amount of sand behind it to the east (HE_O-20). The south side of the creek here shows evidence of a 20 foot down cut (or mass flow) over the last few decades. Coppicing, pruning and replacement of trees is not recommended here, but with windfalls and death of larger trees, replacement by shorter species is recommended. Planting shrubs and small trees along the till capped bluff tops is preferable to taller species here. Dumping yard waste and large organic debris on the bluffs can destabilize the slopes.

CONCLUSIONS

Innis Arden fits into a model of slope instability associated with soils, surficial geology, urbanization and devegetation. In these models (Dunne and Leopold 1978) there are correlations between the times and places of slope instability and the occurrence of certain climatic and geologic conditions. Most slope movement events that get attention are related to a few days of intense precipitation during a general period of inferred high water table. On this basis, future episodes of widespread slope instability are predicted during particularly wet winters on days when approximately 1.5 inches or more of rainfall occurs. For these reasons, historical documentation by Innis Arden residents of how the reserves functioned during times (e.g., the 1996/97 Holiday Storm events or after a heavy snow in 2001 which had a very wet November following) that favor slope movement would be useful to future planning.

How slopes and watersheds are vegetated above can affect what happens to the stability of slopes below. An extreme example of this is piping where sand is exported horizontally along a clay surface resulting in a sink hole at the point of origin. Only Coyote Reserve has a likelihood of this phenomenon occurring and this is unlikely (especially is a storm culvert is diverted here and the canopy maintained. A more likely scenario in Inis Arden is for slope movement to occur along contacts between Esperance Sand and Lawton Clay. Most landslide damage is associated with this zone of particular landslide hazard. Interestingly, a stable till cap is located at and around the mouths of Heron and Eagle Creeks. This has many implications with respect to slope stability. First, gardening and dumping yard waste at the reserve borders or over the bluffs facing the Sound should be avoided. Second, growing shrubs and shorter trees with compact root systems might be better on the ledges than large trees subject to wind throw. Third, grading of these areas to lower slope grades is more likely to induce slides, not prevent them. Fourth, plants (including large trees) should not be removed or pruned above and within the creek canyons above and through the creek beds that slice into this cap just before reaching the Sound. Fifth, all culvert and pipe outlets into these areas should be removed.

On slopes above with deep, sandy Indianola soil large trees with deep roots and no pruning (except to remove diseased branches) are preferred for optimizing slope stability. In runoff areas and creek beds not subject to storm purging, and increase in stem density of riparian species might be best. On moderate slopes above these areas, shorter species are acceptable provided the slope is <15% grade. Ericaceous broad leaf evergreens might provide a suitable cover. In no cases are barren soil or yard waste dumping acceptable. Although alders and maples and other species coppice well, the removal of coarse and small debris associated with this pruning is needed for a variety of reasons associated with slope stability. In particular, in one area of Boeing Creek (BC_O-10) coppicing and the generation of coarse material on the forest floor should cease. Here, reestablishment of the forest may increase slope stability. Overall, the return of the Boeing Creek Reserve to old growth status might create the most stable slope conditions. The increase development of a forest floor can only help the situation here in a sand/clay mixed area.

Restoration of Boeing and Eagle Creeks could be most effective by focusing on lowering the volume of urban storm surges, installation of large channel barriers that slow water movement and slope and trail stabilization. Pruning and tree removal can only be done in these 2 watersheds with care to not affect the slopes and streams below. Reserves associated with Coyote and upper Heron Creek appear less likely to be sensitive to modification. In the upper reserves of Heron Creek there is an opportunity to use shorter species at higher densities in a way that will improve overall stability. Diversion of storm drains from Coyote in particular, but for Heron Creek as well, has the potential to improve overall slope stability. In addition, channel restoration work is recommended for the Blue Heron Reserve complex.

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GLOSSARY

Bioengineering – stream bank stabilization techniques that maintain environmental integrity of the stream and incorporate natural materials such as native vegetation and woody debris.

Evapotranspiration – the loss of water from a habitat that is due to both net evaporation back into the atmosphere and the movement of water by root uptake and loss then through the leaves back into the atmosphere.

Impermeable Layer – refers to a layer that restricts the downward passage of water. An impermeable layer can be caused by 1) compaction; 2) pan formation due to layers caused by cementing substances such as iron, calcium or silica; or, 3) textural change such as coarse loose material like sand overlying a clay or silt bed that has lower permeability.

Lateral Roots – Most roots are near the stump, but some roots extend to other trees. These lateral roots interweave, holding blocks together making a net of roots that span potential failures.

Piping – subsurface material (in particular sand) being carried across an impermeable layer and deposited down slope some distance from its site of origin. Sinkholes are formed directly above the site of water infiltration.

Root Block – the root mass of a tree is concentrated in the shallow soil near the stump creating a block of root-saturated soil that is stronger than the soil around or below it. Failures occur between or below these blocks

Skid Trails – in steep areas, trails that run directly down slope. These are usually created by children who play in the area and mountain bike activity. They can cause extreme erosion and siltation on steep slopes of Indianola sandy loam soil.

Surficial Geology – This is the deposits left on the surface immediately after the recession of ice from Puget Sound approximately 10,000 years ago. Both geologic and soil borders are rarely discrete (having an abrupt transition). Instead their boundaries are more commonly ill-defined. Originally, one deposit type can overlay another (sand over clay is very common). Another reason for ill-defined borders is erosion from one layer onto another. For instance, in Boeing Creek the surficial geology is defined as Lawton Clay, but due to deposits from sand above, the soil is classified as Indianola. In this paper, map borders relate only to horizontal relationships (not vertical profiles). Often, however, clay extends under sand and compacted till is over sand.

APPENDIX I
SOIL FEATURES AND EXPLANATION
DESCRIPTIONS OF SOIL SERIES FOUND IN WESTERN KING COUNTY

Alderwood is soil that develops atop compacted till. This is glacial material that has been compacted by subsequent glacial events; thus, when the final ice cover melts a looser, coarser layer of till is deposited above the compacted till. This latter is referred to as ablation till. Soil that develops above this is called Alderwood. The compacted layer is impervious to water penetration and very resistant to erosion. In the upper parts of Innis Arden and upon the cliffs over the Puget Sound, Alderwood soil and its substrata serve as a protective cap. The soil also prevents drainage resulting in pools of standing water and flooded basements. Maintenance of the alderwood soil is critical to protecting the Innis Arden area. Compacted till serves as a creek bed in much of Blue Heron and Eagle Reserves, but in some areas the creek has cut through the till and is now down cutting into sand or clay.

Qvt Till; compacted at depth with high bulk density and rock content

Indianola is sandy loam that is well drained and has little coarse rocks. Vegetated (and in particular forested) Indianola absorbs water rapidly and is stable with normal runoff. It does, however, erode very rapidly with urban storm surges, when the over story vegetation is disturbed, with heavy trail use or with from foot traffic directly down the slope. Boeing Creek is down cutting through sand and the surrounding slopes are largely Indianola soil. Upper Eagle, Running Water, Grouse, Bear Trail and Coyote Reserves have surface streams running on sand, but many of these areas are very intermittent. Lack of permanent stream courses here are due to 1) lost of vegetation and soil structure; and, 2) due to rapid infiltration into the soil of precipitation.

Qb Beach deposits (Holocene)
Qpf Surficial deposits, undivided (Holocene and Pleistocene)
Qpog Procession drift (Pleistocene)
Qva Advance outwash deposits (Esperance sand)
Qvi Ice-contact deposits
Qvr Recessional outwash deposits
Tpr Renton Formation (late and middle Eocene)

Bellingham and Kitsap soils occur together throughout the reserves in proportions that make it difficult to call them one or the other soil type. In some cases they are only minor components of what is largely an Indianola unit. Bellingham and Kitsap are both derived from clay; therefore, we can assume that the underlying parent material is clay. Kitsap is essentially well-drained silty loam, whereas Bellingham occurs in areas that have sufficient water to cause redox mottling (orange and brown spots) to appear. These are mineral soils, but Bellingham may contain some peat.
These 2 soil series are basically distinguished by slope and drainage (better drainage and slope >8% = KITSAP); silt deposits the former being soils in areas with little slope that are poorly drained, the latter being better drained and on steeper slopes

Qal Alluvium (Holocene)
Qpff Clay and silt (Lawton clay)
Qpfn Whidbey formation (Pleistocene)
Qvic Transitional beds (Pleistocene)
Qvrl Recessional outwash, silt dominated lowland & lacustrine deposits (silt/ clay); slopes generally greater than 8% or well drained

Norma is a soil series that occurs in narrow strips along Heron and Eagle Creeks and perhaps in pockets in Boeing Creek. These soils are in depressions on till plains and drainages formed in old alluvium. They are poorly drained soil formed in alluvium and in this case under conifers and hardwoods with sedges, horsetails and willows growing in it. It has a high water table. It occurs where slopes are generally <3%. The surface layer is black sandy (gritty) loam to 10 inches thick. Soil depth can be down to 60 inches, but generally it is not as thick as Seattle muck. Below this, the subsoil is grayish brown. In Innis Arden these probably represent relict wetlands. A mineral soil with wetland characteristics (peat).

Unlisted (pockets of wetland mineral soil found along floodplains of creeks or in wet pockets atop compacted till).

SOILS CLASSIFIED AT LEVELS OTHER THAN SERIES

Entisol is an order (as opposed to series) classification. It refers to a soil so recent in its origin that no organic matter has accrued and no weathering has occurred. Here, Entisol is applied most commonly to classify large slide area that occurred within the last half of the 20^{th} century. The potential for such catastrophic events within the area is high. Landslides are yearly occurrences around the area. For example, there were about 290 major slides that occurred in Seattle during 1997 season.

Qls Landslide (recent and large)

Qmw Mass wastage deposits (Holocene)

Qv Vashon Drift, undivided

Arent refers to soil derived from anthropogenic influences. In the Innis Arden area much material has been deposited directing into the creeks and still more as compost on the borders of the reserves. This fill includes leaves, grass clippings, branches and even whole trees, tires, slabs of concrete, paint buckets and many shoes. Of greatest concern is the compost that is deposited on the borders of the reserves. This can cause slope overloading and can (over decades and centuries) result in the complete filling in of the reserves.
A modified land (Holocene); fill (anthropogenic); human dumps into wetlands and bays, most notably the Denny regrade, northeast end of the Lake Washington ship canal and Elliott Bay.

APPENDIX II
SOIL SERIES AS DESCRIBE BY NRCS

ALDERWOOD SERIES

The Alderwood series consists of moderately deep to a cemented pan, moderately well drained soils formed in glacial till. Alderwood soils are on glacially modified foothills and valleys and have slopes of 0 to 65 percent. The average annual precipitation is about 40 inches, and the mean annual temperature is about 50 degrees F.

TAXONOMIC CLASS: Loamy-skeletal, isotic, mesic Vitrandic Dystroxerepts

TYPICAL PEDON: Alderwood gravelly ashy loam - forested. (Colors are for moist soil unless otherwise noted.)

Ap--0 to 7 inches; very dark grayish brown (10YR 3/2) gravelly ashy sandy loam, brown (10YR 5/3) dry; moderate fine granular structure; slightly hard, very friable, slightly sticky and slightly plastic; many fine roots; few fine irregular pores; slightly acid (pH 6.2); abrupt smooth boundary. (3 to 7 inches thick)

Bs1--7 to 21 inches; dark yellowish brown (10YR 4/4) very gravelly ashy sandy loam, yellowish brown (10YR 5/4) dry; weak medium subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; many fine roots; many fine tubular and irregular pores; 35 percent pebbles; diffuse smooth boundary; slightly acid (pH 6.2).

Bs2--21 to 30 inches; dark brown (10YR 4/3) very gravelly ashy sandy loam, pale brown (10YR 6/3); dry; weak medium subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; common fine roots; few very fine tubular pores; 40 percent pebbles; slightly acid (pH 6.2); clear wavy boundary. (Combined Bs1 and Bs2 horizons are 15 to 30 inches thick)

2Bs3--30 to 35 inches; 50 percent olive brown (2.5Y 4/4) very gravelly sandy loam, light yellowish brown (2.5Y 6/4) dry and 50 percent dark grayish brown (2.5Y 4/2) cemented fragments with strong brown (7.5YR 5/6) coatings on fragments, light brownish gray (2.5Y 6/2) and reddish yellow (7.5YR 6/6) dry; massive; slightly hard, very friable, nonsticky and nonplastic; few fine roots; common fine tubular and interstitial pores; 45 percent pebbles; moderately acid (pH 6.0); abrupt wavy boundary. (0 to 15 inches thick)

2Bsm--35 to 43 inches; dark grayish brown (2.5Y 4/2) cemented layer that crushes to very gravelly sandy loam, light brownish gray (2.5Y 6/2) dry; dark yellowish brown (10YR 4/4), reddish brown (5Y 4/4), yellowish red (5YR 4/8) and strong brown (7.5YR 5/6) in cracks; massive; extremely hard; extremely firm, nonsticky and nonplastic; few fine roots; few fine tubular pores; 40 percent pebbles; moderately acid (pH 6.0); abrupt irregular boundary. (5 to 20 inches thick)

2Cd--43 to 60 inches; grayish brown (2.5Y 5/2) compact glacial till that breaks to very gravelly sandy loam, light gray (2.5Y 7/2) dry; massive; extremely hard, extremely firm, nonsticky and nonplastic; 40 percent pebbles; moderately acid (pH 6.0).

TYPE LOCATION: Snohomish County, Washington; about 5 miles east of Lynnwood on Maltby road; 200 feet south and 400 feet east of the center of sec. 28. T. 27 N., R. 5 E.

RANGE IN CHARACTERISTICS: The mean annual soil temperature is estimated to range from 47 to about 55 degrees F. These soils are usually moist, but are dry between depths of 8 and 24 inches for 60 to 75 consecutive days in the summer in most years. The soil is strongly acid to slightly acid above the Bsm horizon and slightly acid or moderately acid in the Bsm horizon. Depth to Bsm horizon is 20 to 40 inches. Rock fragments in the particle-size control section range from 35 to 50 percent and include 0 to 10 percent cobbles.

The A horizon has hue of 10YR or 7.5YR, value of 2 or 3 moist, 3 through 5 dry, and chroma of 2 to 4. It has weak or moderate granular structure. Some pedons have an E horizon less than 1 inch thick.

The Bs1 and Bs2 horizons have hue of 10YR or 7.5YR, and value and chroma of 2 through 6 dry or moist. It is very gravelly loam or very gravelly sandy loam and has weak or moderate blocky structure. The Bs1 is gravelly loam in some pedons. This horizon contains none to many hard concretions presumed to be of iron and manganese compounds.

The 2Bs3 horizon, or the 2BC or 2CB horizon has hue of 10YR or 2.5Y, value of 5 through 7 dry, and chroma of 2 through 4 moist and dry. They have redox concentrations in some pedons, but lack depletions of 2 or lower chroma within 30 inches of the surface. These horizons are very gravelly sandy loam or very gravelly loam. They have weak subangular blocky structure or are massive.

The 2Bsm horizon (cemented layer) has hue of 10YR or 2.5Y, value of 4 through 8 dry, and chroma of 1 through 3 moist and dry and is mottled in some pedons. It is very gravelly sandy loam, very gravelly loamy sand, gravelly sandy loam, or gravelly loamy sand when crushed.

COMPETING SERIES: These are the Baldhill, Neausite, Dabob, Fidalgo, and Whistle series. The Baldhill soils are very deep and lack cemented pans and densic materials. The Beaustie and Fidalgo soils are 20 to 40 inches deep to a lithic contact. The Whistle soils are 40 to 60 inches deep to a lithic contact. Dabob soils have an albic horizon and lack densic materials within 60 inches.

GEOGRAPHIC SETTING: These soils are on till plains and moraines at elevations of 50 to about 800 feet. Slope is 0 to 65 percent. The soils formed in glacial till. Alderwood soils are in a cool marine climate. The summers are cool and dry, and the winters are mild and wet. Mean annual precipitation ranges from 25 to 60 inches, most of which falls as rain from November through March. Mean January temperature is 38 degrees F, mean July temperature is 60 degrees F, and mean annual temperature is 50 degrees F. The growing season (28 degrees F) is about 200 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Beausite, Dick, Everett, Hoogdal, Indianola, Kitsap, Norma, Quilcene, Skipopa and Whidbey series. All of these soils except Whidbey soils lack a cemented layer within 40 inches. In addition, the

Beausite soils have a lithic contact at 20 to 40 inches. Dick, Hoogdal, Indianola, Kitsap, and Skipopa soils have less than 35 percent coarse fragments. Everett soils are sandy-skeletal. McKenna soils have an aquic moisture regime. Norma soils have an aquic moisture regime of less than 35 percent coarse fragments in the upper part of the control section. Quilcene soils are in a fine family. Whidbey soils have an E horizon 2 to 5 inches thick and have a higher base status.

DRAINAGE AND PERMEABILITY: Moderately well drained; slow to medium runoff; moderately rapid permeability to the cemented layer and dense glacial till and very slow permeability through them. A perched water table is as high as 18 to 36 inches at times from January through March..

USE AND VEGETATION: Used mostly for woodland, field crops, hay and pasture, orchards, vineyards, wildlife habitat, watershed, and non-farm uses. The native vegetation is Douglas-fir, western hemlock, western redcedar, and red alder with an understory of salal, Oregon-grape, western brackenfern, western swordfern, Pacific rhododendron, huckleberry, red huckleberry, evergreen huckleberry, and Orange honeysuckle.

DISTRIBUTION AND EXTENT: Northwestern Washington; MLRA 2. The series is extensive.

MLRA OFFICE RESPONSIBLE: Portland, Oregon

SERIES ESTABLISHED: Snohomish County, Washington 1936.

REMARKS: Classification only changed 4/94 because of recent amendments to Soil Taxonomy, except the horizon nomenclature was updated, and fragments of ortstein and ortstein was changed to cemented fragments and a cemented layer. Classification changed 1/2000 from mixed, mesic Vitrandic Durochrepts to isotic, mesic Vitrandic Dtstroxerepts based on revision to Soil Taxonomy. Diagnostic horizons and features include:

Ochric epipedon
Cambic horizon - from 7 to 35 inches
Cemented pan - from 35 to 43 inches assumed to be cemented with iron, aluminum, and organic matter.
Densic material - from 43 to 60 inches
Vitrandic feature - assumed to be from 0 to 30 inches
Oxyaquic feature - perched water table at 18 to 36 inches at times from January to March.

All depths to diagnostic horizons and features noted in the range of characteristics are measured from the top of the first mineral horizon. More investigation is needed to differentiate the Alderwood from the Dabob series.

ADDITIONAL DATA: Partial data available for this series. Sample # S71WA-033-002, Riverside Lab., 11/73. National Cooperative Soil Survey, U.S.A.

BELLINGHAM SERIES

The Bellingham series consists of very deep, poorly drained soils formed in loess, alluvium, and lacustrine sediments. These soils are in depressions. Slopes of 0 to 3 percent. The average annual precipitation is about 48 inches and the mean annual temperature is about 50 degrees F.

TAXONOMIC CLASS: Fine, mixed, superactive, nonacid, mesic Vertic Endoaquepts

TYPICAL PEDON: Bellingham silty clay loam - pasture. (Colors are for moist soil unless otherwise noted. All textures are apparent field textures.)

Ap--0 to 5 inches; black (10YR 2/1) silty clay loam, dark gray (10YR 4/1) dry; strong fine granular structure; hard, friable, moderately sticky and moderately plastic; many fine roots; moderately acid (pH 5.8): abrupt smooth boundary. (4 to 6 inches thick)

Bg1--5 to 8 inches; gray (5Y 5/1) silty clay, light gray (N 7/) dry; few fine distinct yellowish brown (10YR 5/8) redox concentrations; weak medium prismatic structure; very hard, firm, moderately sticky and moderately plastic; many fine roots; many medium tubular and vesicular pores; moderately acid (pH 6.0); clear smooth boundary. (2 to 13 inches thick)

Bg2--8 to 14 inches; dark gray (5Y 4/1) silty clay, light gray (N 7/) dry; few fine distinct yellowish brown (10YR 5/8) redox concentrations; moderate medium prismatic structure; very hard, firm, very sticky and very plastic; common fine roots; many medium tubular and interstitial pores; thin patchy pressure faces on peds and lining pores; slightly acid (pH 6.2); clear smooth boundary. (4 to 18 inches thick)

Bg3--14 to 22 inches; gray (5Y 5/1) clay, light gray (N 7/) dry; many medium distinct yellowish brown (10YR 5/8) redox concentrations; moderate medium prismatic structure; very hard, firm, very sticky and very plastic; common fine roots; many medium tubular and interstitial pores; continuous pressure faces on peds; slightly acid (pH 6.4); clear smooth boundary. (0 to 10 inches thick)

Bg4--22 to 48 inches; dark gray (5Y 4/1) clay, white (5Y 8/1) dry; many medium distinct yellowish brown (10YR 5/8) redox concentrations; moderate medium prismatic structure; very hard, firm, very sticky and very plastic; few fine roots; common fine relic grass leaves; few medium tubular and interstitial pores; continuous pressure faces on peds; neutral (pH 6.6); gradual smooth boundary. (0 to 40 inches thick)

Bg5--48 to 60 inches; gray (5Y 5/1) silty clay, white (5Y 8/1) dry; many medium distinct yellowish brown (10YR 5/8) redox concentrations; moderate medium prismatic structure; very hard, firm, very sticky and very plastic; common fine roots; many medium tubular and interstitial pores; continuous pressure faces on peds; slightly acid (pH 6.4)

TYPE LOCATION: Thurston County, Washington; 8 miles northwest of Olympia, about 2,100 feet east and 400 feet south of the NW corner sec. 34, T. 19 N., R. 3 W.

RANGE IN CHARACTERISTICS: Thickness of the solum is 40 to 60 inches or more. The particle-size control section is 35 to 60 percent clay and 0 to 2 percent rounded pebbles. The mean annual soil temperature is 47 to 52 degrees F. It is assumed the solum to a depth of 40 inches has a linear extensibility of 2 to 3 inches.

The A horizon has value of 2 or 3 moist, 3 through 5 dry, and chroma of 1 through 3. Some pedons have strong brown to dark brown redox concentrations. This horizon has moderate or strong granular or angular blocky structure. It is moderately acid or slightly acid.

The Bg horizon has hue of 10YR, 2.5Y, 5Y, 5BG, or 5GY, value of 3 through 6 moist, 5 through 8 dry, and chroma of 0 through 3. It has few to many fine and medium dark reddish brown, yellowish red, strong brown, yellowish brown, or dark yellowish brown redox concentrations. It is clay loam, silty clay loam, silty clay, or clay. This horizon has weak or moderate prismatic or angular blocky structure. It has weak or distinct pressure faces on some peds. It is moderately acid through moderately alkaline.

The C horizon, where present, has hue of 2.5Y, 5Y, or 5B, value of 3 through 6 moist, 4 through 8 dry, and chroma of 1 or 2 moist and dry. It has yellowish red or strong brown redox concentrations. This horizon is clay loam, silty clay loam, silty clay, or clay with some pedons having thin layers of sandy loam or silt loam. It is moderately acid through moderately alkaline.

COMPETING SERIES: There are no competing series.

GEOGRAPHIC SETTING: Bellingham soils are in depressions at elevations of 20 to 600 feet. Slopes are 0 to 3 percent. These soils formed in loess, alluvium and lacustrine sediments. The climate is characterized by cool, dry summers and cool, moist winters. Average annual precipitation is 25 to 60 inches. Average January temperature is about 39 degrees F; average July temperature is about 64 degrees F; and the mean annual temperature is about 50 degrees F. Frost-free season is 150 to 210 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Alderwood, Clallam, Elwha, Everett, Kitsap, Labounty, McKenna, Sadie, Skipopa, and Whatcom soils. All of these soils lack an aquic moisture regime except Labounty and McKenna soils. Also, Alderwood soils have a cemented layer. Clallam, Elwha, McKenna, and Sadie soils have a densic contact with dense very compact glacial till at depths of 20 to 40 inches. Everett soils are sandy-skeletal. Kitsap soils are fine-silty. Labounty soils are fine-loamy. Skipopa soils have an argillic horizon with a silt loam surface mantle that qualifies as aquandic. Whatcom soils are fine-loamy.

DRAINAGE AND PERMEABILITY: Poorly drained; ponded or very slow runoff; slow permeability. A water table occurs at or near the surface from November through April unless the soil is drained.

USE AND VEGETATION: Bellingham soils are used primarily for cropland and pasture. Grass-legume hay is the principal crop. Native vegetation is predominantly red alder, western redcedar, bigleaf maple, western hemlock and Douglas-fir with an understory of western swordfern, trailing blackberry, western brackenfern, thimbleberry, salmonberry, huckleberry, and Douglas spirea.

DISTRIBUTION AND EXTENT: This series is of moderate extent in the Puget Sound Area and on the north end of the Olympic Peninsula; MLRA 2.

MLRA OFFICE RESPONSIBLE: Portland, Oregon

SERIES ESTABLISHED: Eastern Puget Sound Basin, Washington, 1909.

REMARKS: Diagnostic horizons and other features are: Soil is not considered a vertic intergrade based on similar soil data from lab pedon #81P0515. Characterization data are available; sample numbers S77WA-9-3, S81WA-073-3. Diagnostic horizons and features recognized in this pedon are an ochric epipedon and a gleyed cambic horizon from 5 to 60 inches.

In the past this series has been interpreted as having an apparent or a perched water table. The series is considered to have Endo saturation. For areas mapped with perched water tables and a moist or dry zone is present below the layer perching the water, a new series will need to be proposed.

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INDIANOLA SERIES

The Indianola series consists of deep, somewhat excessively drained soils formed in sandy glacial drift and minor amounts of volcanic ash. Indianola soils are on terraces, terrace escarpments, eskers, and kames at elevations of near sea level to 1,000 feet. Slopes are 0 to 90 percent. The mean annual precipitation ranges from 30 to 55 inches and the mean annual temperature is about 50 degrees F.

TAXONOMIC CLASS: Mixed, mesic Dystric Xeropsamments

TYPICAL PEDON: Indianola loamy sand-forested. (Colors are for moist soil unless otherwise stated.)

A--0 to 6 inches;dark reddish-brown (5YR 3/3) loamy sand, brown (10YR 5/3) dry; weak coarse and medium subangular blocky structure; soft, very friable, nonsticky and nonplastic; many very fine and few coarse and medium roots; common fine tubular pores; neutral (pH 6.8); abrupt smooth boundary. (1 to 9 inches thick)

Bw--6 to 13 inches; dark reddish-brown (5YR 3/4) loamy sand, pale brown (10YR 6/3) dry; weak coarse and medium subangular blocky structure; soft, very friable, nonsticky and nonplastic; common very fine and few medium roots; few fine tubular pores; neutral (pH 6.8); clear smooth boundary. (3 to 10 inches thick)

BC--13 to 25 inches; dark brown (10YR 4/3) loamy sand, pale brown (10YR 6/3) dry; massive; soft, very friable, nonsticky and nonplastic; few very fine and fine roots; few very fine tubular pores; 5 percent rounded pebbles; neutral (pH 6.6); clear smooth boundary. (3 to 12 inches thick)

C1--25 to 35 inches; dark yellowish-brown (10YR 4/4) sand, light brownish gray (2.5Y 6/2) single grain; loose; few very fine roots; few very fine tubular pores; 5 percent rounded pebbles; neutral (pH 6.8); gradual wavy boundary. (4 to 24 inches thick)

C2--35 to 60 inches; olive brown (2.5Y 4/4) sand; light brownish-gray (2.5Y 6.2) dry single grain; loose; few very fine roots; many fine interstitial pores; 5 percent rounded pebbles; neutral (pH 6.6).

TYPE LOCATION: Thurston County, Washington; about 2 miles southeast of Tumwater, north end of Munn Lake near Department of Game boat launching site; 2,200 feet east and 2,550 feet north of the southwest corner sec. 1, T. 17 N., R. 2 W.

RANGE IN CHARACTERISTICS: These soils are usually moist but are dry in the moisture control section for 60 to 75 consecutive days following summer solstice. The mean annual soil temperature is estimated to range from 47 to 52 degrees F. Reaction ranges from neutral to strongly acid throughout. The particle-size control section contains 0 to 15 percent rock fragments.

The A horizon has hue of 10YR, 7.5YR, or 5YR, value of 2 or 3 moist, 3 through 6 dry, and chroma of 1 through 6 moist and dry.

The B horizon has hue of 10YR, 7.5YR, or 5YR, value of 2 through 4 moist, 4 through 6 dry, and chroma of 1 through 4 moist and dry. It is loamy fine sand or loamy sand.

The BC horizon has hue of 10YR or 2.5Y, value of 4 or 5 moist, 6 or 7 dry, and chroma of 3 or 4 moist and dry. It is loamy fine sand, loamy sand, fine sand, or sand.

The C horizon has hue of 10YR, 2.5Y or 5Y, value of 4 through 6 moist, 5 through 7 dry, and chroma of 2 through 4 moist and dry. It is loamy fine sand to sand.

COMPETING SERIES: These are the Birdsview, Greenwater, Keystone, and Pilchuck series. Birdsview soils are dry for 45 to 60 consecutive days following the summer solstice. Greenwater soils have 5 to 25 percent pumice in the control section. Keystone soils are dry for 75 to 90 consecutive days following the summer solstice. Pilchuck soils have chroma of 2 or less throughout the control section.

GEOGRAPHIC SETTING: Indianola soils are on terraces, terrace escarpments, eskers, or kames at elevations of near sea level to 1,000 feet. Slopes are 0 to 90 percent. These soils formed in sandy glacial drift and minor amounts of volcanic ash. They are in a maritime climate of cool dry summers and mild wet winters. Mean annual precipitation ranges from 30 to 55 inches most of which falls between October and April. The average January temperature is 36 degrees F., the average July temperature is 62 degrees F., and mean annual temperature is 50 degrees F. The frost-free season ranges from 150 to 210 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Alderwood, Cassolary, Everett, Hoypus, Kitsap, Nisqually, Quilcene, Sinclair, Spanaway, and Tokul soils. Alderwood, Sinclair, and Tokul soils have a duripan at a depth of 20 to 40 inches. Cassolary soils are fine-loamy. Everett, Hoypus and Spanaway soils are sandy-skeletal. Kitsap soils are fine- silty. Nisqually soils have an umbric epipedon. Quilcene soils have a fine control section and are underlain by weathered shale at depths of 20 to 40 inches.

DRAINAGE AND PERMEABILITY: Somewhat excessively drained; slow runoff; rapid permeability.

USE AND VEGETATION: Mostly woodland and pasture. Native vegetation is Douglas-fir, western redcedar, western hemlock, red alder and bigleaf maple, with an understory of salal, Oregon-grape, red huckleberry, western bracken-fern, western swordfern, trailing blackberry, evergreen huckleberry and vine maple.

DISTRIBUTION AND EXTENT: Puget lowlands in Northwestern Washington. The series is of moderate extent.

MLRA OFFICE RESPONSIBLE: Portland, Oregon

SERIES ESTABLISHED: Kitsap County, Washington, 1935.

ADDITIONAL DATA: Laboratory Data S74-WA-61-5, Riverside, California.

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KITSAP SERIES

The Kitsap series consists of very deep, moderately well drained soils formed in lacustrine sediments. Kitsap soils are on terraces and terrace escarpments and have slopes of 0 to 70 percent. The mean annual precipitation is about 37 inches. The mean annual temperature is about 50 degrees F.

TAXONOMIC CLASS: Fine-silty, isotic, mesic Aquandic Dystroxerepts

TYPICAL PEDON: Kitsap silt loam - pasture. (Colors are for moist soil unless otherwise noted.)

Ap--0 to 6 inches; very dark grayish brown (l0YR 3/2) silt loam, grayish brown (l0YR 5/2) dry; moderate fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; moderately acid (pH 5.8); abrupt smooth boundary. (3 to 6 inches thick)

Bwl--6 to l0 inches; dark brown (l0YR 4/3) silt loam, pale brown (l0YR 6/3) dry; moderate fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; few very fine pores; many 2 to 5 mm light brown (7.5YR 6/4) concretions; moderately acid (pH 6.0); clear wavy boundary. (3 to l2 inches thick)

Bw2--l0 to l7 inches; brown (l0YR 4/3) silty clay loam, pale brown (l0YR 6/3) dry; moderate medium subangular blocky structure; hard, firm, moderately sticky and moderately plastic; many very fine roots; common very fine pores about 3 percent fine pebbles; few 2 to 5 mm light brown (7.5YR 6/4) concretions; few silt balls; few krotovinas; slightly acid (pH 6.4); clear wavy boundary. (4 to 22 inches thick)

BC--l7 to 32 inches; grayish brown (2.5Y 5/2) silty clay loam, light gray (2.5Y 7/2) dry; many large prominent strong brown (7.5YR 5/6) redox concentrations; moderate medium subangular blocky structure; hard, firm, moderately sticky and moderately plastic; few very fine roots; common very fine pores; slightly acid (pH 6.5); clear irregular boundary. (0 to 35 inches thick)

C--32 to 60 inches; light olive brown (2.5Y 5/4) silt loam and silty clay loam, light brownish gray (2.5Y 6/2) dry; very fine and fine stratification; hard, firm, moderately sticky and moderately plastic; few roots; few very fine pores; tongues of grayish brown (2.5Y 5/2) material like the B3 horizon; neutral; (pH 6.6).

TYPE LOCATION: Pierce County, Washington; l00 feet north of corner of l04th St. and 80th Ave.; 2,050 feet west and 2,750 feet south of the northeast corner of sec. 5, T. l9 N., R. 4 E.

RANGE IN CHARACTERISTICS: These soils are usually moist but are dry in the moisture control section for 45 to 60 consecutive days following summer solstice. The mean annual soil temperature is estimated to range from 50 to about 53 degrees F. These soils range from moderately acid to neutral throughout. Coarse fragments in the control section average 0 to 5 percent by volume. Depth to redoximorphic features with a chroma of 2 or less is 5 to 24 inches.

The A horizon has value of 2, 3 or 4 moist, 4, 5 or 6 dry, and chroma of 2 or 3 moist or dry. It is silt loam or loam.

The Bw horizon has value of 3 through 5 moist, 5 through 7 dry, and chroma of 3 or 4 moist or dry. It is silt loam or silty clay loam, and has weak or moderate blocky structure. The BC horizon has hue of l0YR or 2.5Y, value of 4 through 6 moist, 6 through 8 dry and is prominently mottled. It has blocky or prismatic structure or is massive.

The C horizon has hue of l0YR, 5Y or 2.5Y, value of 5 or 6 moist, 6 through 8 dry, chroma of 2 through 4 moist and dry and is mottled. In some pedons bluish gray (5B 5/l) gleying is prominent in root channels. This horizon is stratified silt, silt loam and silty clay loam. Some pedons contain thin strata of silty clay, silt, or fine sand.

COMPETING SERIES: This is the Aloha series and the similar Giles and Saxon series. Aloha soils have an average soil temperature of 54 to 56oF and lack strata of silty clay loam in the lower part of the particle- size control section. Giles and Saxon soils lack grayish colors or mottles in the subsoil and are well drained. Also, Saxon soils have a dense laminated silt, clay, or silty clay loam B horizon.

GEOGRAPHIC SETTING: Kitsap soils are on terraces and terrace escarpments at elevations ranging from near sea level to about 500 feet. Slopes are 0 to 70 percent. The soils formed in lacustrine sediments. These soils occur in a mild marine climate. Summers are cool and dry and winters are mild and wet. The mean annual precipitation ranges from 30 to 45 inches. The mean January temperature is 39 degrees F., mean July temperature is 61 degrees F., and mean annual temperature is 50 degrees F. The frost-free season is 160 to 200 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Alderwood, Everett, Harstine, and Indianola soils. These soils have less than 18 percent clay in the control section. Alderwood and Harstine soils have a duripan. Everett soils are sandy-skeletal, and Indianola soils are sandy.

DRAINAGE AND PERMEABILITY: Moderately well-drained; slow or medium runoff; slow permeability.

USE AND VEGETATION: Mostly forests and some cropland and pasture. Native vegetation is Douglas-fir, western hemlock, western redcedar, red alder, bigleaf maple, and willows, with understory of western brackenfern, western swordfern, salal, Oregon-grape, trailing blackberry, red huckleberry, vine maple, evergreen huckleberry, red elderberry, and wild ginger.

DISTRIBUTION AND EXTENT: Northwestern Washington. The series is of moderate extent.

MLRA OFFICE RESPONSIBLE: Portland, Oregon

SERIES ESTABLISHED: Kitsap County, Washington, 1934.

REMARKS: Classification changed 4/94 and 1/00 because of amendments to Soil Taxonomy. The 0 to 10 inch depth is estimated to have >5 percent volcanic glass and >0.4 percent Al + 1/2 Fe by acid-oxalate.

ADDITIONAL DATA: Partial laboratory data available on this soil. Pedon # S77WA-061-30, NSSL, Lincoln, NE.

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NORMA SERIES

The Norma series consists of deep, poorly drained soils formed in old alluvium in depressions on glacial till plains and drainageways. Slopes are 0 to 3 percent. Average annual precipitation ranges from 35 to 60 inches.Mean annual temperature is 50°F.

TAXONOMIC CLASS: Coarse-loamy, mixed, superactive, nonacid, mesic Aquandic Humaquepts

TYPICAL PEDON: Norma ashy loam - pasture. (Colors are for moist soil unless otherwise noted.)

Ap--0 to 9 inches; very dark gray (10YR 3/1) ashy loam, gray (10YR 5/1) dry; moderate fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many fine, medium and coarse roots; many very fine tubular pores; slightly acid (pH 6.2); abrupt wavy boundary. (6 to 10 inches thick)

2Bg--9 to 28 inches; dark grayish brown (2.5Y 4/2) sandy loam, light brownish gray (2.5Y 6/2) dry; common medium prominent yellowish brown (10YR 5/8) redox concentrations; weak medium subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; few fine roots; many very fine pores; slightly acid (pH 6.4); clear wavy boundary. (10 to 35 inches thick)

2Cg--28 to 60 inches; dark gray (5Y 4/1) sandy loam, light gray (5Y 6/1) dry; common fine prominent red (2.5Y 4/6) yellowish brown (10YR 5/6) redox concentrations; massive; slightly hard, friable, nonsticky and nonplastic; few roots; many very fine pores; slightly acid (pH 6.4).

TYPE LOCATION: Snohomish County, Washington; 2,350 feet north and 1,590 feet west of southeast corner of sec. 29, T. 27 N., R. 5 E.

RANGE IN CHARACTERISTICS: Mean annual soil temperature is estimated to range from 48 to 52 degrees F. The particle-size control section is 0 to 30 percent coarse fragments, 5 to 15 percent clay, and more than 15 percent fine and coarser sand.

The A horizon has value of 2 or 3 moist, 4 or 5 dry, and chroma of 1 through 3. It is very strongly acid to slightly acid. It has moderate fine or medium granular structure. Some pedons have an AB horizon.

The 2Bg horizon has hue of 10YR, 2.5Y, or 5Y, value of 4 or 5 moist, 5 or 6 dry, and chroma of 1 or 2. It has prominent redox concentrations with high values and chromas. It is fine sandy loam, loam, gravelly sandy loam, sandy loam, or silt loam. It is moderately acid or slightly acid.

The 2Cg horizon has variegated colors and is sandy loam or loamy sand. It is very gravelly loamy sand to silty clay loam below 40 inches in some pedons. It is moderately acid or slightly acid.

COMPETING SERIES: This is the Keowns series. Keowns soils have free carbonates at a depth of 12 to 24 inches.

GEOGRAPHIC SETTING: Norma soils are in depressions on glacial till plains and drainageways at elevations from near sea level to about 1,000 feet. They formed in old alluvium and have 0 to 3 percent slopes. Average January temperature is 38 degrees, average July temperature is 64 degrees F, and mean annual temperature is 50 degree F. The average annual precipitation ranges from 35 to 60 inches, most of which falls as rain during the winter months. The frost-free season ranges from 160 to 200 days. The growing season (28 degrees F) is 200 to 240 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Alderwood, Everett, Shalcar, and Tukwila soils. Alderwood soils have a xeric moisture regime and are loamy-skeletal. Everett soils have a xeric moisture regime and are sandy-skeletal. Shalcar and Tukwila soils are Histosols.

DRAINAGE AND PERMEABILITY: Poorly drained; high water table is as high as 1 foot above to 1 foot below the surface of the soil at times from November to April unless drained; slow to ponded runoff; moderately rapid permeability to a depth of 40 inches and ranges from moderately rapid to slow below 40 inches.

USE AND VEGETATION: When drained, these soils are used for growing row crops and pasture. Native vegetation is western redcedar, red alder, big leaf maple, and some western hemlock, with an understory of western swordfern, western brackenfern, trailing blackberry, thimbleberry, salmonberry, red huckleberry, salal, willow, cascara buckthorn, skunkcabbage, stinging nettle, Oregon-grape, vine maple, sedges, and rushes.

DISTRIBUTION AND EXTENT: Puget Sound Basin of western Washington; MLRA 2. This series is of moderate extent.

MLRA OFFICE RESPONSIBLE: Portland, Oregon

SERIES ESTABLISHED: Snohomish County, Washington, 1938.

REMARKS: Classification only changed 4/94 because of recent amendments to Soil Taxonomy. At 0 to 9 inch depth the percent of volcanic glass is estimated to be >5 and percent by ammonium-oxalate extract is >0.4. Diagnostic horizons and features recognized in this pedon are an ochric epipedon from the surface to 9 inches and a gleyed cambic horizon from 9 to 28 inches. The base saturation (by NH4OAc) of these soils is assumed to increase to more than 50 percent within 60 inches.

National Cooperative Soil Survey
U.S.A.

APPENDIX III
MOUNTAIN BEAVERS, SOILS AND SLOPE STABILITY

Mountain Beavers are active throughout the reserves. Mountain Beaver activity in the Seattle area is restricted to sandy Indianola soil. In several cases the mountain beavers were depositing sandy soil directly into the stream. These rodents eat plant roots and do not prefer tree roots; nonetheless, if herbaceous and shrub roots are available, the tree roots will be avoided by the animals.

In low or moderate densities the presence of Mountain Beavers is not necessarily bad. These organisms mix the soil thus benefiting trees with improved aeration and nutrient flux. They eat tree roots. In low population numbers, mountain beavers may be beneficial to tree growth and soil development, but at higher densities may have a net negative effect on slope stability. On the other hand they eat roots and may cause tree death if present in too large of numbers. The overall net effect of these animals on slope stability and tree condition is unknown. A reasonable assumption is that in small numbers they are beneficial, but large populations are detrimental.

Mountain beavers prefer habitats with small and large diameter woody debris, forage plants and uprooted stumps. They colonize areas with soft soil in drainages. These are all characteristic of the Innis Arden Reserves. A good way to limit Mountain Beaver tree root consumption is to provide them with sufficient alternative food sources such as sword fern and salal (Hacker and Coblentz 1993). Populations of the rodents will be encouraged if trees are cut or topped and the material is left on the slopes.

APPENDIX IV

GENERAL STATUS OF CREEKS

Boeing Creek has serious slumping, undercutting and down cutting both upstream of Hidden Lake and within the reserve itself. The creek runs year round and has been shown by the Shoreline Community College Environmental Technology program to spawn salmon. Coyote, Heron and Eagle Creeks ran all summer despite our dry winter. The upper most reserves (Coyote, Bear Trail and Grouse) have flows only during the wettest storms and these are short lived.

Down cutting and Bank Undercutting – Stream down cutting was classified into 5 classes: 1) nonexistent where vegetation grows flush with the stream; 2) Present where at least 6 inches of recently exposed, unvegetated bank is visible; 3) Moderate where 1 to 3 feet of exposed bank occurs; 4) Severe where more than 3 to 5 feet of bank is exposed; and 5) Extreme where more than 5 feet of down cutting is believed to have occurred within the last few decades. A good example of Extreme down cutting is in Boeing Creek between North Pond Dam and Hidden Lake. Bank undercutting is classified as present or absent. Extreme down cutting is present at the mouths of both Eagle and Heron Creeks. Moderate to Severe down cutting is noted in Boeing Creek Reserve, Blue Heron and Eagle Reserve. In some cases down cutting appears to be greater than 10 vertical feet. The result of down cutting is increased plant and soil slumping and canyon formation. The general effect is rapid increasing of slope resulting in an ever increasing cycle of erosion and tree falls. Down cutting has other consequences. In particular the mouths of Eagle and Heron Creeks both have the potential for catastrophic slides in the near future to creek down cutting and pipe outlets onto creek banks and bluffs.

Stream Blockages - Culverts –Many culverts are clogged with as much as 75% of capacity lost. Given a rain-on-snow event such as the Holiday storm of 96-97, water can readily back up and then overflow the roads resulting in washouts and even piping. This problem is also one of the easiest and cheapest to solve. Indeed, some neighbors told me that during heavy storms they went down and cleared the culverts in Coyote and Grouse Reserves. In Coyote, Bear Trail and Grouse Reserves there is little chance of massive slope failures, but some houses are in danger of tilting in with the ever present slope movement. In addition, a small debris/snow/ice slide could jam the culvert and lead to road overflow if snow from an earlier event covered the ground.

Culvert Outlet Down Cutting – outlets that were originally placed on the soil surface of slopes having runoff that erodes the soil immediately surrounding the outlet. With time this develops into a gully and the pipe's terminal end may become suspended resulting in increased power for storm runoff to downcut into the evergrowing gully. One of the most serious examples of this is at the mount of Eagle Creek just north of the creek over the bluff. Two newer pipes also were found to empty directly into the cascade of Heron Creek. These all should go directly to the Sound, not the creek.

The Railroad – Railroad culverts, in contrast to the reserves above, are clear of obstructions. Most, if not all, of the culverts are unsuited for fish passage.

Water Management on Inactive Roads – The trail in Boeing Creek runs along an abandoned road; thus, management procedures applicable to roads converted to trails elsewhere might apply here. To deactivate roads no longer required for vehicular travel, the road surface should be modified to permit water to flow with little or no maintenance. The degree of modification depends on whether the road will be abandoned or opened for limited access. Putting a road to bed provides adequate drainage and slope stabilization to protect the road (it this case to protect for use as a foot trail). Methods used to deactivate roads include installing water bars, removing culverts, pulling back unstable fill, out sloping roads and improving ditch lines.

Slope Movement – can be visualized at the soil surface; slower movement is detected by the presence of slanting or bowed trees.

Piping and sink holes – Definition of problem (see 1997 EIS for Boeing Creek Holiday Storm Event at Shoreline Library). Given the large expanse of sandy soil and heavy rainfall often experienced in the winter here, the possibility of sinkhole formation is always present. Homes located on Vashon till are relative safe from this phenomenon, but homes located on sand (and especially those located on sand above clay) are more likely to succumb to sinkholes that result from piping.

Trees – Cutting or pruning trees will cause roots to die and this will lead to slope instability. Some trees are more suited to topping than others and some trees are more suited to slow moving slopes; no trees, however, are adapted to rapid moving slopes massive slides. Nonetheless, some trees such as willows and poplars can withstand partial covering of the base of their trunks. No conifers in the Pacific Northwest can survive heavy siltation or soil deposition about their base.

APPENDIX V
HUMAN CAUSES OF SLOPE INSTABILITY

Considerable landslide modification accompanies urbanization, and is a contributing factor in many landslides. In fact, 80% of the landslides involved one or more of the human causes. Activity of children is quite high in the reserves. This activity is associated with mountain bike riding and bike jumping (ramps are built on the trail of upper Blue Heron). At places where swings have been placed on trees, skid trails come in from both sides and both the skid trails and swing activity is damaging the slope and may cause some large trees to be undercut.

The most common way people in the central Puget Sound decrease soil stability is:

- By removing or harming existing vegetation (especially large trees with extensive root systems).
- By improperly treating the issues of drainage
- By increasing the weight of the structures sitting on top or along steep slopes

Diversion of excess water onto the slope was one of the most common human influences, contributing to well over 40 percent of the landslides. The water most often came from roofs and paved areas, but sewers, water lines, culverts, ponds, and ditches were also sources.

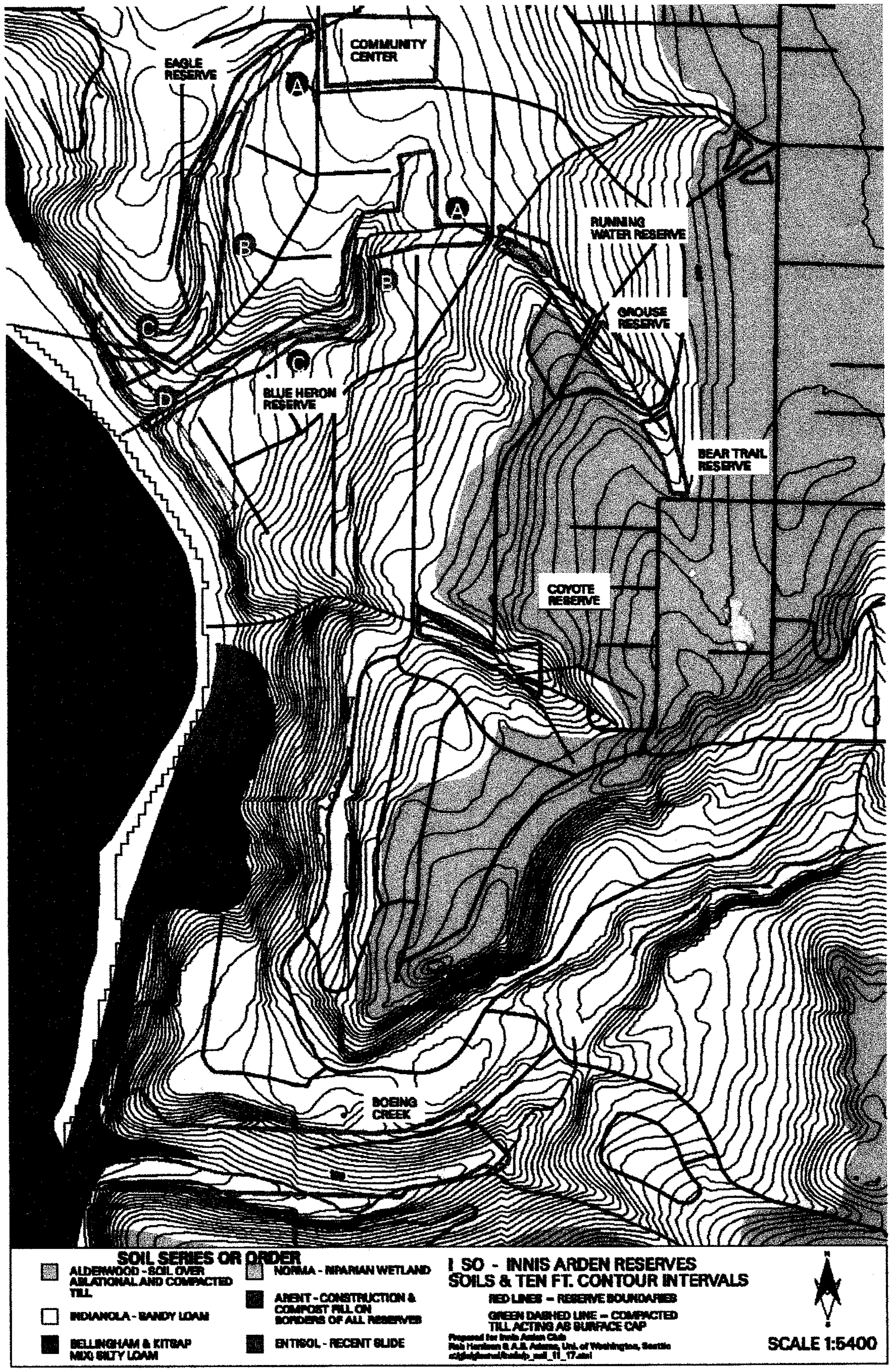
Hillside excavations, primarily roadcuts, but also those due to landscaping and construction activities, are a factor in more than 40 percent of the landslides. In one case the excavation resulted in the immediate failure of a large mass of adjacent material, but most of these slides involved only a thin layer of surficial material resting upon an old, artificially steepened slope.

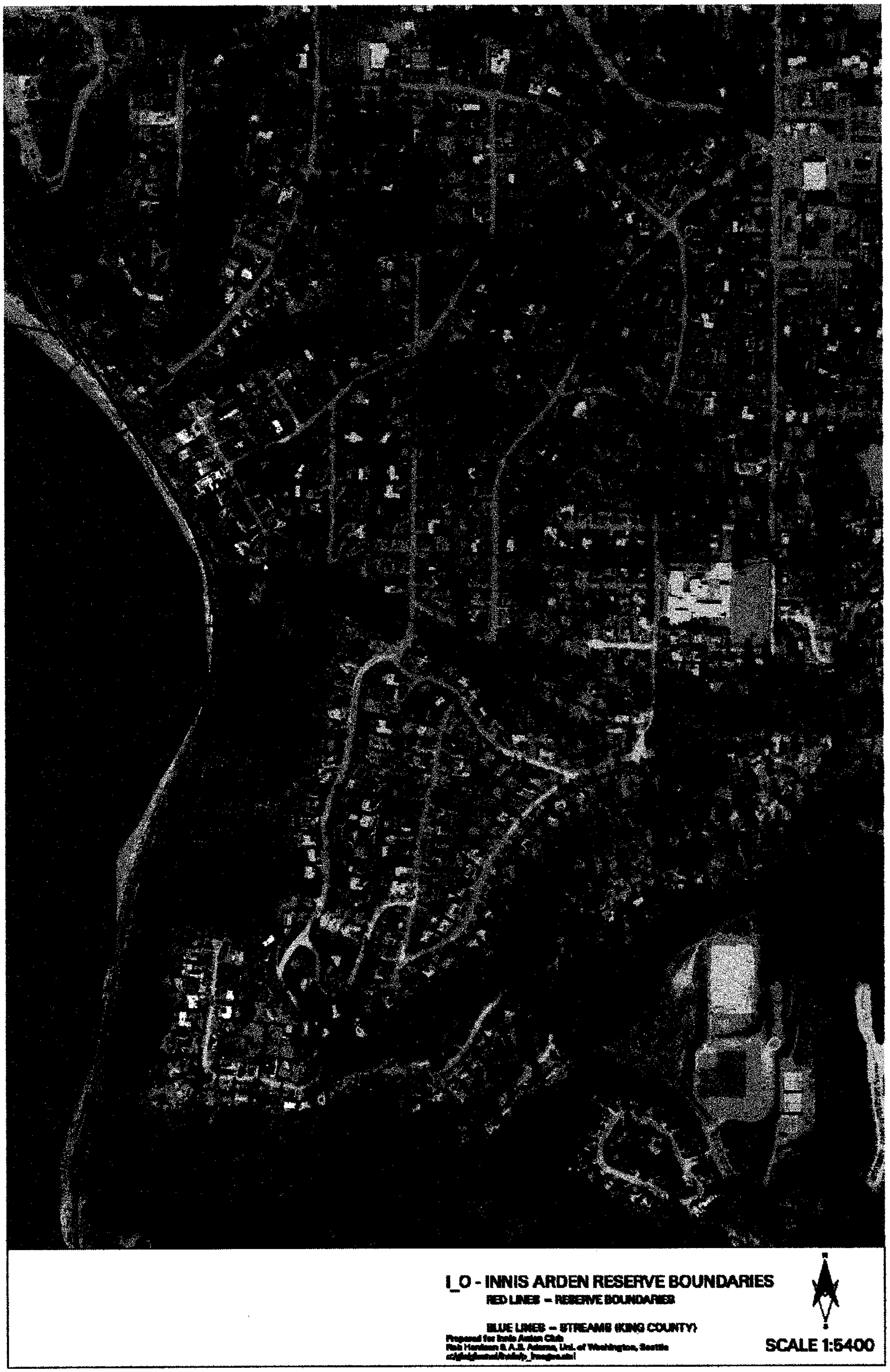
Artificial fills placed over impermeable deposits are often unstable, for reasons discussed in the previous section. Even relatively small fill failures may cause substantial damage if they remove foundation support or if they slide into a structure below. Over 30% of the landslides involved some artificial fill.

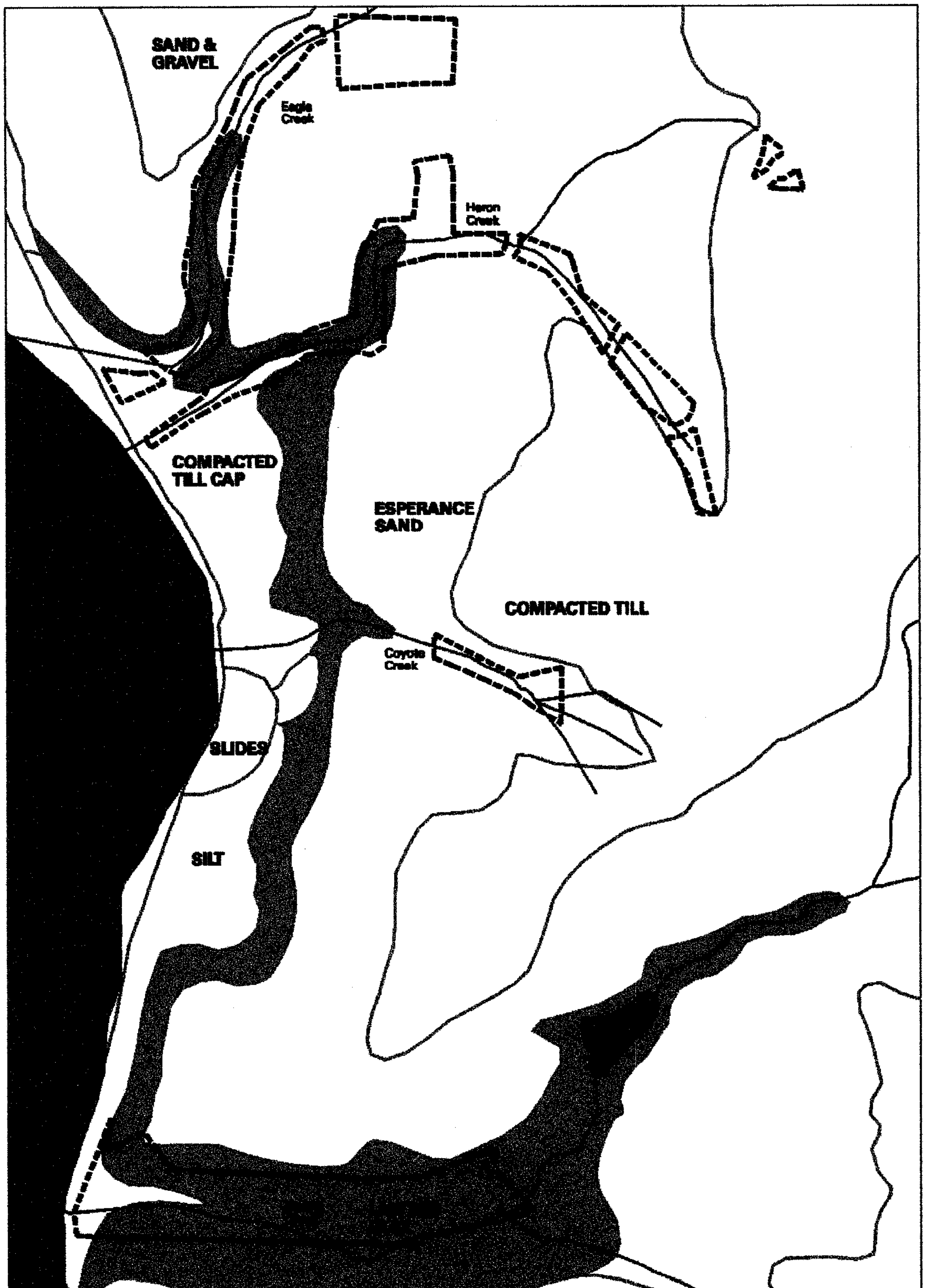
A few landslides (10%) are the result of retaining wall failures, due to inadequate design, construction, or maintenance. It is outside the scope of our work to comment on these.

Some Puget Sound lowland soils are well-suited for trails in flat areas, but unsuitable for trails on steep slopes (Indianola soil falls into this categogy). In some cases, this can actually cause catastrophic slope failure, often associated with the trails undercutting or otherwise destabilizing large trees. This is more so if the trees have dead or dying roots. A good example of a trail with such problems is between the 2 makeshift plank bridges in the middle of Eagle Creek Reserve. This trail runs on the north side of the stream on sandy soil. The problem is aggravated by heavy activity of children in this area. The problem might be alleviated if the trail were moved to the south side of the creek and then cross back over to the north bank at a lower makeshift bridge.


CY_O - COYOTE RESERVE
RISK ASSESSMENT - MODERATE
COYOTE RESERVE
CITY OF SHORELINE RESERVE
PARCELS
LAWTON CLAY
RECENT SLIDE(S)
1 SLOPE OVERBURDER FROM FILL
2 12" STORM CULVERT & GULLY
3 PUDDLING STORM WATER
4 OPEN BUT INACTIVE CULVERT
5 SURFACE SAND MOVING OVER CLAY
6 CLAY/SAND CONTACT ON SLOPE >30%
7 RECENT SLIDES ASSOCIATED WITH #6
1:3600
200 0 200 Feet


COMMUNITY CENTER
EAGLE RESERVE
RUNNING WATER RESERVE
GROUSE RESERVE
BLUE HERON RESERVE
BEAR TRAIL RESERVE
COYOTE RESERVE
BOEING CREEK
SOIL SERIES OR ORDER
ALDERWOOD - SOIL OVER ABLATIONAL AND COMPACTED TILL
INDIANOLA - SANDY LOAM
BELLINGHAM & KITSAP MIX) SILTY LOAM
NORMA - RIPARIAN WETLAND
ARENT - CONSTRUCTION & COMPOST FILL ON BORDERS OF ALL RESERVES
ENTISOL - RECENT SLIDE
I SO - INNIS ARDEN RESERVES
SOILS & TEN FT. CONTOUR INTERVALS
RED LINES = RESERVE BOUNDARIES
GREEN DASHED LINE = COMPACTED TILL ACTING AS SURFACE CAP
SCALE 1:5400


I_O - INNIS ARDEN RESERVE BOUNDARIES
RED LINES – RESERVE BOUNDARIES
BLUE LINES – STREAMS (KING COUNTY)
Prepared for Innis Arden Club
SCALE 1:5400



SURFICIAL GEOLOGY - Lawton Clay extends north to south and into Boeing Creek. Between Coyote & Eagle Creeks, a sand/clay complex is bordered east and west by compacted till. In the center of Innis Arden where till is not present above the Sound, sand and silt slide down a steep slope across the clay to the Sound.

I_G - INNIS ARDEN SURFICIAL GEOLOGY

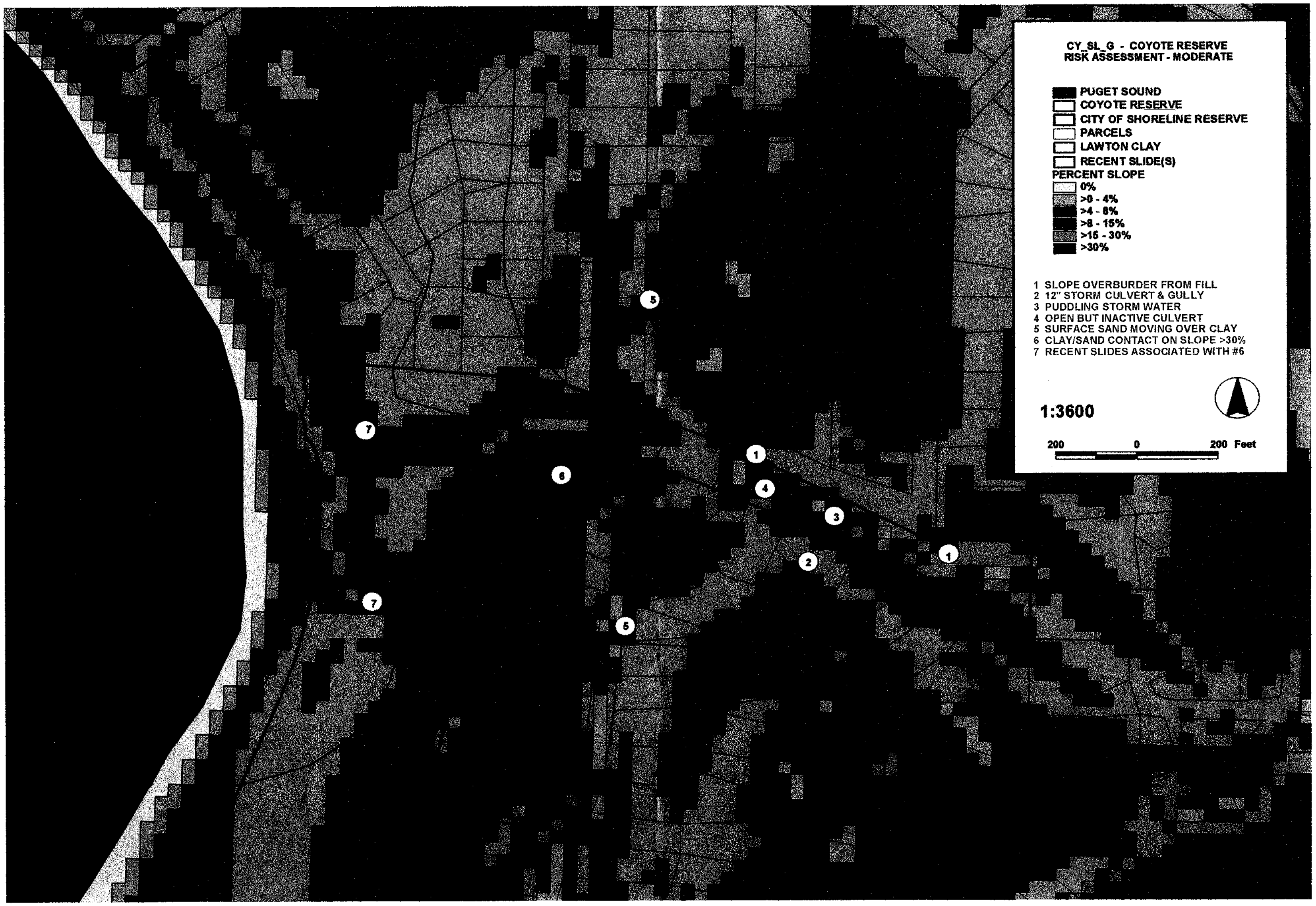
RED LINES DENOTE SURFICIAL GEOLOGIC BORDERS

BLACK DASHED LINES -- RESERVE BOUNDARIES

BLUE LINES -- STREAMS (KING COUNTY)

SCALE 1:5400


EAGLE RESERVE
COMMUNITY CENTER
RUNNING WATER RESERVE
GROUSE RESERVE
BLUE HERON RESERVE
BEAR TRAIL RESERVE
COYOTE RESERVE
BOEING CREEK
SLOPE CLASSES
30% OR GREATER
LESS THAN 8% TO 4%
LESS THAN 30% TO 15%
LESS THAN 4% TO 0%
LESS THAN 15% TO 8%
I_SL - INNIS ARDEN RESERVES,PARCELS, ROADS & EXTREME SLOPES > 60 FT WIDE (RED)
BLACK DASHED LINES – RESERVE BOUNDARIES
GREEN DASHED LINE – COMPACTED TILL ACTING AS SURFACE CAP
SCALE 1:540


CY_SL_G - COYOTE RESERVE
RISK ASSESSMENT - MODERATE
PUGET SOUND
COYOTE RESERVE
CITY OF SHORELINE RESERVE
PARCELS
LAWTON CLAY
RECENT SLIDE(S)
PERCENT SLOPE
0%
>0 - 4%
>4 - 8%
>8 - 15%
>15 - 30%
>30%
1 SLOPE OVERBURDER FROM FILL
2 12" STORM CULVERT & GULLY
3 PUDDLING STORM WATER
4 OPEN BUT INACTIVE CULVERT
5 SURFACE SAND MOVING OVER CLAY
6 CLAY/SAND CONTACT ON SLOPE >30%
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1:3600
200 0 200 Feet